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ADSORPTIVE CLAYS OF THE TEXAS GULF COAST

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ABSTRACT

Numerous clay pits containing an abundance of material suitable for the clarification and purification of petroleum products are operated along the Texas Gulf Coastal Plain. Much of the original material has altered sufficiently to form adsorptive clay of usable quality. Optical, chemical, and x-ray studies indicate that the principal mineral constituent of the clays as mined is montmorillonite. Microscopic textures and structures, when well preserved, are significant of origin.

Many beds represent the result of alteration in situ of volcanic ash. However, substantial amounts of kaolinite, halloysite, and allophane occur in some deposits. In certain deposits alteration has been so complete as to obliterate direct evidence of the origin of the clay.

The waxy character of many moist clay layers is a convenient indicator in the field. Laboratory study shows that waxy clays contain more nearly pure montmorillonite than other types which are soft, granular, and kaolinitic. The luster may be attributed to unusual hydration characteristics of montmorillonite. Kaolinitic mixtures occur in the

northeastern part of the clay belt, whereas the more nearly pure montmorillonite occurs in the southwestern part.

A review of the literature, correlated with field observations, indicates that the fuller's earths of eastern Texas formed during the Eocene, and Oligocene or Miocene epochs. Correlation of physical, chemical, and optical properties with adsorptive capacity has been attempted. The influence of mineralogical features on adsorptive capacity may be summarized as follows: impurities lower adsorptive capacity; microscopic structures and textures are apparently not related to adsorptive efficiency; the montmorillonite lattice structure permits high adsorption; amount and degree of alteration of original material to clay materially affect adsorptive capacity; origin by transportation of clay introduces granular impurities and lowers adsorptive power; high percentages of removable bases and water seem to accompany high adsorptive capacity; montmorillonite is the most highly adsorptive clay mineral studied.

INTRODUCTION

The clays described in this paper were collected during the summer of 1936 in connection with a program of clay-mineral study which has been carried on at Columbia University for a number of years. The specimens were collected by Dr. Paul F. Kerr who also provided notes concerning field occurrences. An attempt was made to obtain material from the then known occurrences of adsorptive clays of economic importance in Texas.

The deposits studied occur in at least six counties in Texas, along a broad crescent-like curve more or less parallel, and about one hundred miles from the Gulf Coast. All lie within a narrow belt which extends from the vicinity of the Louisiana border for about two hundred and forty miles southwest to Gillett, which is forty-three miles southeast of San Antonio. Similar clays are said to occur along the extension of this belt as far south as Mexico.

The deposits to be discussed may be listed as follows:

Zavalla	(1)	Bennett and Clark Deposit
Zavalla	(2)	Haralsen Deposit
Luce		Trinity Clay Products Company Deposit
Riverside	(1)	Continental Oil Company Deposit
Riverside	(2)	Texas Company Deposit
Fayette	(1)	Carr-Brown Tract
Fayette	(2)	Parker-Ivy Tract
Fayette	(3)	J. A. K. Tract
Fayette	(4)	Fleck-Darby Tract
Fayette	(5)	Lena Deposit of the Texas Company
Gonzales	(1)	Oscar Dubois Tract
Gonzales	(2)	Kent Dubois Tract
Gonzales	(3)	Gillett Deposit

GEOLOGIC OCCURRENCE AND HISTORY

The clay deposits included in the present study occur in a fairly narrow belt of Tertiary Gulf Coastal Plain strata. All are bedded and either flat lying, or exhibit a low angle of inclination. Structural disturbances are of minor importance. Localization of alteration, or lenticularity of deposition, however, limits the distance to which any one stratum may

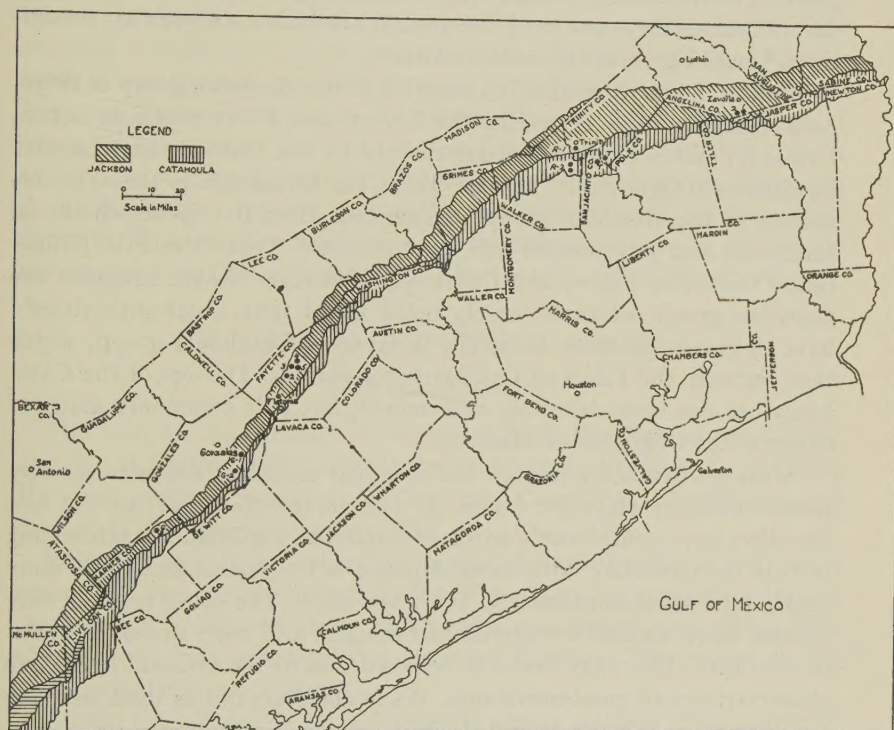


FIG. 1. Geographic and geologic distribution of the Texas Gulf Coastal clay belt deposits. (See reference 1.)

be traced. The deposits parallel the general strike of Tertiary strata and occur in the Jackson group (Eocene) and in the Catahoula formation (Oligocene or Miocene)¹ as mapped by the United States Geological Survey, the University of Texas, and various geologists and oil companies of Texas (Fig. 1).

In Texas the Jackson group includes all uppermost Eocene strata above the top of the Claiborne group. The name Fayette is used as a formational name to include undifferentiated strata above the Yegua

(Eocene) and below the Catahoula, or, where present, the Frio (Oligocene or Miocene).² The Jackson group lies conformably upon the Yegua, and is overlain unconformably by the Catahoula and Frio formations.³ No attempt has been made here to separate the deposits into the various members of the Jackson group designated by Renick.⁴

The Jackson group consists of shallow-water, marine, and beach deposits. The rocks include sand which is lignitic in places, and argillaceous and tuffaceous clays and tuffs. Frequently the beds are somewhat fossiliferous,⁵ and in general dip southwestward.

The Catahoula formation is a member of the Gueydan group of Oligocene or Miocene age. It overlies the Fayette and Frio formations unconformably, and is overlain unconformably by the Oakville and Lagarto formations (Oligocene).^{3,4} In east Texas the Catahoula is the only formation of the Gueydan group represented. Here it consists chiefly of sandstone and interbedded ash. In southwest Texas the Frio (Oligocene)⁶ formation below, and Catahoula formation above, comprise the Gueydan group, which is largely made up of tuffs. Some authorities^{2,7} have dropped the name Gueydan in favor of Catahoula group, which then includes the Frio and Catahoula formations. The age of the Catahoula has not been definitely determined, but it is commonly assigned either to the Oligocene or Miocene.

In the southwestern part of the clay belt economic deposits of waxy montmorillonite clays are found. In the northeastern part of the belt the clays have considerable admixed kaolinitic material. An interesting feature in connection with these deposits is the concentration of more nearly pure montmorillonite in the waxy clays. The other types of clay contain more kaolinitic material and are soft and more or less granular in structure. The waxy luster is believed due to the unusual hydration characteristics of montmorillonite. Waxy clays are not as thick as those containing kaolinitic material. In spite of appreciable amounts of kaolinitic material present in the northeastern clays, their adsorptive power is sufficient to make them economically useful as decolorizing agents^{8,9,10,11} in petroleum refining.^{12,13}

Igneous activity, which started in Yegua time, became more pronounced in the middle and late Jackson epoch,^{7,14} and continued with even greater intensity in Catahoula time. Volcanic ash was deposited over a considerable area and was "picked up by streams which redeposited it along with muds to form the light-colored 'kaolinite' beds, which were sorted from the other sediments in such a way as to produce the chalky-looking fuller's earth deposits."³

On the basis of formational thickness and size of included volcanic

boulders, it is believed that the source of volcanic ash was southwest of the present deposits. If this is true, it would be expected that more ash would occur in the southwest than at the localities where it is found at present. Although this condition is fulfilled in the Catahoula strata, some authorities do not believe it has been fulfilled in the Jackson strata. It has been suggested that the ash was ejected from volcanoes with considerable force, and then drifted for great distances northeast.¹⁵ Streams eroded the deposits and then redeposited the ash in lenticles. Some of the material is believed to have been blown into dunes by winds. Although some of the fine ash probably traveled considerable distances, possibly from the Trans-Pecos region, the larger size and subangular shape of much of the coarser material in the Catahoula ash indicate that it could not have been transported far. Bailey¹⁶ therefore, has suggested that some of the volcanoes were located in the near vicinity of the present deposits. This complex stratigraphy¹⁷ is significant in view of the impure nature and irregular occurrence and distribution of the deposits studied.

DESCRIPTIONS OF INDIVIDUAL DEPOSITS

ZAVALLA DEPOSITS

The Zavalla clays include two deposits: (1) the Bennett and Clark deposit, 9.3 miles south of Zavalla in Angelina County, and (2) the Haralsen property operated by Coen and Company, 2.6 miles west of deposit (1) in Angelina County (Fig. 2).

Both deposits show similarities in mineral constituents, optical properties, and structural characteristics. The clays are complex mixtures consisting of montmorillonite and kaolinite, together with about 25% of other minerals, principally quartz and feldspar. The texture is fine and laminations are distinct.

Zavalla (1)—The clay pit is located in strata mapped as belonging to the Jackson group of Eocene age. The clay beds of the deposit attain a considerable thickness, more than 20 feet of clay-bearing strata being exposed in places. It seems likely that the clay strata have a total thickness in the neighborhood of 30 feet (Fig. 3). The strata comprising this thickness, however, are far from uniform in quality.

The clay is for the most part bluish or greenish gray. It lacks the waxy appearance characteristic of most high grade bentonite, and the close-packed laminated structure present in many fuller's earths. In some places it grades into a black shale, and in the lower part of the clay layer there is a considerable amount of carbonaceous matter.

Examination in thin section shows that about 75% of the material is a complex mixture of at least two, and probably three, clay minerals.

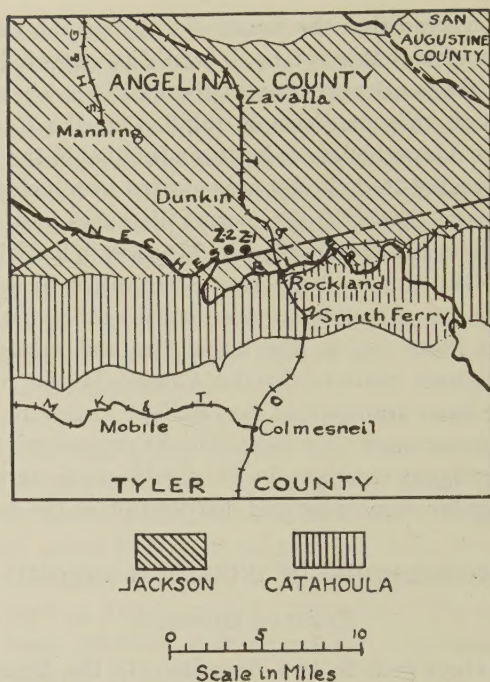


FIG. 2. Position of Zavalla clay deposits on the geologic map of Texas. (See reference 1.)

Description	Strata.	Thickness
Soil		2-6'
Sandy layer (ash)		2'
Fine sandy clay		10'
Blue clay		5½'
Sandy lens		1'
Gray clay below Sandy layer		14'
Black shale with carbonaceous matter		2'+

FIG. 3. Generalized section of the Zavalla (1) pit.

About 25% of the material consists of glass and granular impurities, chiefly quartz, plagioclase, and muscovite. A small amount of pyrite occurs in streaks and patches sparsely scattered through the clay material. Limonite is present in very small amounts as surface stain.

The clay-mineral constituents include kaolinite and halloysite, occurring in relatively coarse grains and patches in a fine-textured matrix which appears to consist of a mixture of kaolinite, halloysite, and montmorillonite. Owing to the extremely fine texture of this mixture, the exact proportions of the constituents present are indeterminable, but from the nature of the *x*-ray and chemical data, it would appear that montmorillonite, if actually present, forms only a minor percentage of the mixture. Because of the intimate mixture of clay minerals it is difficult to determine the indices. The result of an approximate determination of the optical constants of the clay-mineral constituents is as follows: kaolinite $n = 1.565 \pm .003$ mean index, birefringence .005; halloysite $n = 1.542 \pm .003$ mean index, .003-.004 birefringence; montmorillonite $n = 1.536 \pm .003$ mean index, birefringence .022, 2V (-) small. The value given for the index of montmorillonite is within the range of published data, but owing to the intimate manner in which it is mixed with the other clay-mineral constituents, satisfactory determination of the indices is not feasible. This is also true of the birefringence given for halloysite which is high and may be explained as being due to the presence of admixed kaolinite. For all three minerals the elongation is (+), and the extinction slightly inclined to the cleavage.

The average grain size of both grit and clay particles, not including the coarse patches, is about .01-.02 mm. The clay particles are for the most part haphazardly oriented. The bedding is indistinct, both in hand specimen and in thin section. Some micro-faulting has taken place, shown by offset of the laminae. The streaks, patches, and veinlets of coarsely crystalline kaolinite and halloysite are sedimentary in origin and appear to be related to recrystallization along the micro-fractures in the clay.

In the clay bed described there is no trace of any structure which would indicate origin by alteration of a volcanic ash bed.^{18,19} The structure and general character of the clay in thin section are characteristic of a normal fine-textured sedimentary deposit. However, just above the clay bed examined there is a two foot layer of sandy bentonite exhibiting vitroclastic structure. Although this should not be taken as evidence of volcanic origin of the underlying clay, it is at least suggestive that the main clay bed may be bentonitic in part, and has been so highly altered to clay, and contaminated by sedimentary material as to obliterate any original vitroclastic structure which might have been present. The sedimentary aspect of the clay may be due to reworking and redepo-

sition of an original ash by stream action as explained in a subsequent section on origin.

X-ray diffraction patterns obtained from the raw blue clay show lines which correspond most closely to a mixture of kaolinite and quartz. It appears that the principal clay-mineral constituent is kaolinite. It is not surprising that in such a mixture the diffraction lines of halloysite and montmorillonite are obscured due to the stronger patterns given by both kaolinite and quartz.

Zavalla (2)—The Zavalla (2) deposit occurs in strata mapped as belonging to the Jackson group of Eocene age. In 1936 the clay bed was

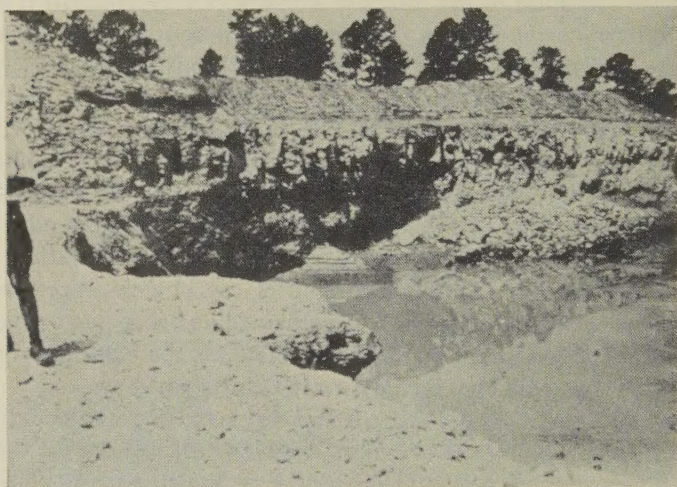


FIG. 4. A general view of the Zavalla (2) pit. The bench in the foreground marks the top of the clay.

being mined by Coen and Company. Clay exposures in the pits were about ten feet in thickness. The upper five feet consisted of grayish white clay, and the lower five feet of blue clay. A hard, massive sandstone about four feet in thickness overlies the clay strata. Local operators at the pit have reported the presence of fossiliferous and lignitic strata beneath the clay (Fig. 4).

Study of thin sections of the blue clay from the deposit shows that it is a complex mixture. The principal constituents appear to be montmorillonite and kaolinite. In addition there are impurities estimated at approximately 25% of the material. These range in size up to .1 mm. and consist chiefly of granular quartz and acid feldspar. Disseminated

through the clay are minor amounts of pyrite cubes occurring as minute single cubes, and as clusters which are several millimeters in diameter. The pyrite is evidently of secondary origin. Numerous microscopic rosettes of gypsum occur in the clay, and appear to form several per cent of the material. Minor impurities include zircon, muscovite, and tourmaline. An unidentified isotropic mineral of high relief is present in small amounts.

The clay material is extremely fine-grained, average size of the particles being about .05 mm. For this reason accurate estimation of the amounts of kaolinite and montmorillonite present in thin section is diffi-

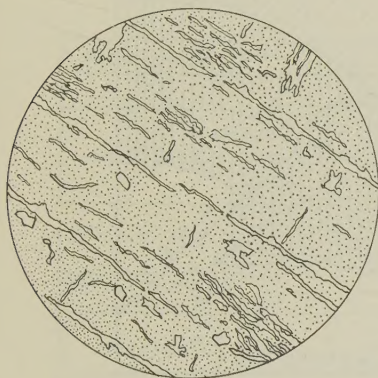


FIG. 5. Diagram illustrating oriented-shred structure of montmorillonite, thought to be the result of pressure-packing. $\times 25$.



FIG. 6. Diagram showing arrangement of montmorillonite shreds around a pyrite crystal. $\times 25$.

cult. The mean index of refraction of the montmorillonite is $n=1.525$, the birefringence .02. The value given for the index is high due to admixed kaolinite.

In the clay as a whole, a considerable percentage of clay particles is oriented sub-parallel to the lamination. The degree of this orientation, however, is variable from one lamina to another. Some parts of the sections show only rudimentary orientation, but exhibit a characteristic shred-like structure. This structure consists of shreds of montmorillonite crystals, or groups of crystals, aligned in a roughly parallel manner similar in appearance to aligned sericite flakes (Figs. 5, 6). It is believed that this structure is due to packing of clay particles, resulting from pressure-orientation.

Though massive in hand specimen, the material shows an indistinct lamination in thin section. Sections examined show no evidence of ash

structure, the petrographic characteristics of the clay being those of a normal sedimentary deposit. However, it may be that this is a deposit in which the alteration and presence of sedimentary material have obscured all traces of original ash structure.

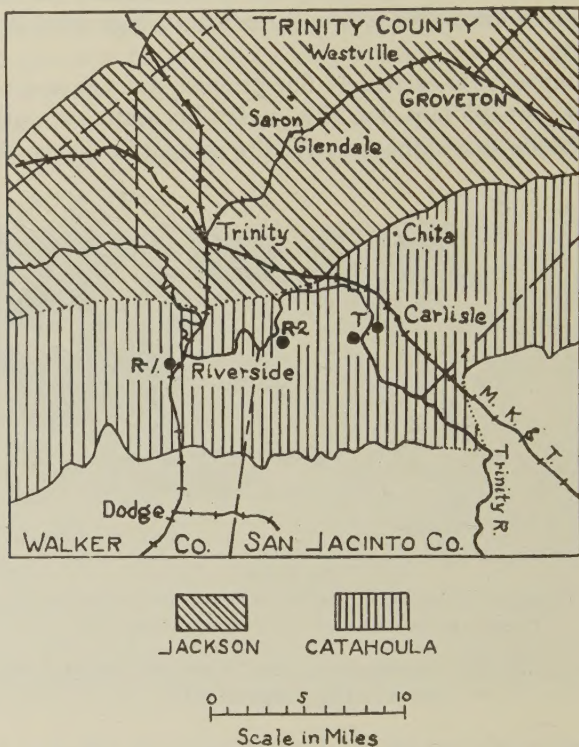


FIG. 7. Position of Trinity clay deposits on the geologic map of Texas.
(See reference 1)

X-ray diffraction patterns of material from the deposit indicate that montmorillonite and kaolinite are present. In addition, lines due to quartz and feldspar impurities occur in the patterns.

TRINITY DEPOSITS

The Trinity clays include three deposits. The Luce deposit operated by the Trinity Clay Products Company is located at Luce, 12.5 miles southeast of Trinity, in Trinity and San Jacinto counties. Riverside (1), operated by the Continental Oil Company, is located one mile west of Riverside in Trinity County, Riverside (2), operated by the Texas Company, is located 5 miles northeast of Riverside in Walker County (Fig. 7).

The clays are in strata mapped as belonging to the Catahoula formation of Oligocene or Miocene age. In several ways the Trinity deposits are the most complex of the clays examined. They appear to include several types of clays. The Luce deposit consists of volcanic ash which has partly altered to bentonite, and shows well-preserved vitroclastic structure. The two Riverside deposits, however, are of doubtful origin. The petrographic features of the clays are those of ordinary sedimentary clays, but there is a possibility that they are bentonitic.

Luce Deposit—The clay section exposed in the pit at the Luce deposit consists of about four feet of sandstone caprock, beneath which are three

Description	Strata	Thickness
Sandstone		4'±
Flinty clay		3'
Soft fractured clay		18"
Coarse laminated clay (chief clay)		5'
Sandstone		

FIG. 8. Generalized section of the Luce deposit.

feet of a hard, flint-like clay, followed by eighteen inches of soft, highly fractured clay, and five feet of coarse, laminated clay resembling fuller's earth in physical appearance. Sandstone occurs beneath the lowest clay layer of the deposit. It would appear, even from a brief field examination, that the clays of this deposit are lenticular and quite variable in character (Fig. 8).

Representative material from the chief clay layer, and from the upper flinty layer was studied. Examination of thin sections of material from both clay beds indicates that they represent volcanic ash now partly altered to mixtures of halloysite and montmorillonite, with some unaltered glass. The halloysite represents sedimentary contamination.

A minor amount of grit, mostly quartz and feldspar, is present. In

spite of the alteration, the structure of the original volcanic ash is clearly preserved in each case. In both beds the degree of alteration of ash to clay is variable from point to point, so that in places minute lenses or laminae of essentially unaltered ash may be seen; these are less abundant in the chief clay layer than in the upper flinty layer (Fig. 9).

The material as a whole is of complex composition. It consists of shard-shaped areas with a variable amount of interstitial coarsely crystalline montmorillonite, individual crystals of which may reach maximum diameters of .6 mm. The interstitial montmorillonite is evidently forming by alteration of the original glass shards, which can be seen to

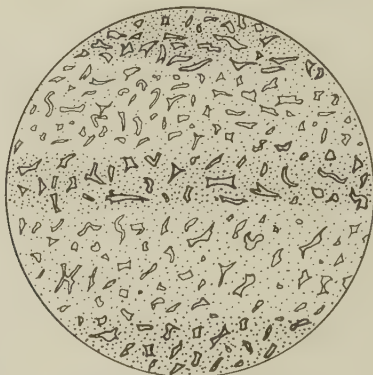


FIG. 9. Diagram of altered volcanic ash from the main clay bed at Luce, showing bedding and glass shards. $\times 25$.

grade into the clay mineral in certain places. Although this montmorillonite varies in amount in different parts of the slides, it constitutes a fairly large percentage of the material. Vermicular crystals of what appears to be montmorillonite occur occasionally.

The relict shards have an average original length of .1 mm. and are of uncertain composition. Most of them are birefringent, but some are isotropic and may be partly altered glass.²⁰ They show moderate relief in the coarsely crystalline montmorillonite, and are thought to represent an intermediate product in the alteration of glass to montmorillonite, although they do not have the appearance of montmorillonite.

The clay appears to contain about 3–8% grit, mostly quartz and acid feldspar. The amount varies from one lamina to another, some laminae being practically free from impurities. A few lenticular areas are stained with limonite. In certain laminae oriented structure is poorly developed.

Material from the chief clay layer was found to consist of about 75%

of clay material, 20% unaltered ash, and 5% of grit. The clay material is variable in character and appears to consist principally of montmorillonite, but there is also a considerable amount of halloysite in streaks and patches irregularly distributed through the sections. Laminae consisting of nearly pure glass alternate with laminae almost completely altered to clay. The index of refraction of montmorillonite is $\alpha = 1.490 \pm .003$, $\gamma = 1.512 \pm .003$, birefringence .022, elongation (+), $-2V$ small.

In material from the upper flinty layer, unaltered ash constitutes from 30 to 40% of the mixture. The remaining 60%–70% appears to be equally divided between montmorillonite and halloysite, except for a few per



FIG. 10. Photograph of the fuller's earth bed at Riverside (1).

cent of grit. Some kaolinite may be present. The general character of the flinty layer is similar to that of the chief clay layer. However, in general the flinty material is somewhat more uniform and more regularly bedded. The indices of refraction are: $\alpha = 1.519 \pm .003$ and $\gamma = 1.539 \pm .003$; birefringence .020; $-2V$ small. These values are high, probably due to admixed halloysite. The refractive index of halloysite is variable with $\gamma = 1.555$ maximum.

X-ray diffraction patterns obtained from the chief clay material show lines corresponding to those given by montmorillonite. Patterns obtained from the upper flinty layer, however, show additional lines characteristic of halloysite. These results confirm the conclusion, based on microscopic studies, that halloysite is present in considerably smaller amounts in the main clay bed than in the flinty layer.

Riverside (1)—The Riverside (1) deposit includes a number of clay pits which occur in strata mapped as belonging to the Catahoula formation. The clay strata are about 12 feet in thickness and dip about 2 or 3

degrees to the southeast. In general the beds exhibit a lenticular tendency. The overburden at the pits is small, varying from 0 to 10 feet (Fig. 10).

The fuller's earth just beneath the soil cover is quite hard. This is thought to be due to moisture loss. On the whole, the clay appears to be rather low grade, containing sand and light-colored nodular impurities.

In thin section the clay material has been found to consist of a mixture of several clay minerals, with an estimated 25% of granular impurities. The clay minerals present include kaolinite, halloysite, allophane (?), and montmorillonite. The principal impurities are quartz and feldspar,



FIG. 11. Diagram illustrating replacement of angular quartz and feldspar grains by clay. $\times 115$

with minor amounts of opal, muscovite, glass or amorphous silica, limonite and scattered grains of a zeolitic mineral. These impurities are angular in character, the grains varying in size from one lamina to another.

Because of the intimate and complex mixture of the clay, the determination of optical constants of the various clay mineral constituents has not been found feasible.

An interesting feature in connection with the clay is the occurrence of pseudomorphs of clay after quartz and feldspar. In some cases clay has completely replaced angular grains of quartz and feldspar (Fig. 11).

The clay has a distinctive structure, but it does not fit well into any definite structural class. It resembles granular montmorillonite in appearance, although the true structure is perhaps flaky rather than granular. In hand specimen the material is massive, but in thin section it is arranged in well-developed laminae, consisting alternately of material with

an average grain size of about .05 mm., and material with an average grain size of about .025 mm.

Orientation is variable from one lamina to another, and is not developed to a high degree except in the case of the finer bands which may be fairly well oriented.

The clay bed which was being worked in 1936 shows no trace of any structure which would suggest origin by alteration of an original volcanic ash. On the contrary, its characteristics are those of a fine-textured sediment. In numerous places in thin section, the montmorillonite occurs as grains, which resemble ordinary detrital grains, as if the clay represented a montmorillonite silt. In this case the granular structure may be a direct result of the mode of origin. If this is not a sedimentary clay, it at least contains a considerable percentage of material which was contributed by normal processes of sedimentation, probably in shallow water. Thin sections of associated clay from the same pit show a poorly-preserved vitroclastic ghost structure. The montmorillonite may have been derived by alteration of an impure water-deposited ash, but this is not clear in the sections examined.

It seems probable that the material from Riverside described by M. N. Broughton,²¹ and collected by Dr. John T. Lonsdale, came from some clay bed or pit other than the ones examined in connection with this study. Broughton describes numerous glass shards and divitrified bubble walls not found in material recently studied.

Broughton refers to a letter received by Dr. John T. Lonsdale from Dr. Paul F. Kerr in connection with material submitted by the former for *x*-ray analysis. In his letter Dr. Kerr stated that the four samples submitted from Riverside and Lena do "not appear to be either a kaolin or a montmorillonite type of clay. The four samples appear to agree with the sedimentary clay type mentioned . . . in the *Journal of Sedimentary Petrology*.²² This type of clay may not represent a valid mineral species. We have not yet determined whether it represents a distinct mineral . . . The *x*-ray patterns give numerous lines that do not resemble the lines of any other clay minerals." Further *x*-ray work supports these conclusions regarding the material sent to Dr. Kerr.

However, *x*-ray examination of the material collected by Dr. Kerr and studied in connection with this work, indicates that it consists of kaolinite and quartz. A few of the diffraction lines are somewhat weaker than those of standard patterns of kaolinite; this is probably due to the complex and impure nature of the material. The montmorillonite lines have been obscured by stronger lines of kaolinite and quartz. This *x*-ray evidence also supports the belief that the material from Riverside

collected by Dr. Lonsdale came from some bed or pit other than the one described in this study.

Riverside (2)—The Riverside (2) deposit is made up of an upper and a lower fuller's earth stratum. The upper stratum is about 9 to 12 feet in thickness and appears to rest upon an ash bed. This clay layer contains considerable amounts of gypsum occurring in veinlets. The lower fuller's earth stratum beneath the ash bed is exposed along the creek just north of the pit. This lower bed contains veinlets of opaline or chalcedonic silica. The exposures examined occur in strata mapped as belonging to the Jackson group.

Thin-section examination of the clay material shows it to consist of a complex mixture of clay minerals with about 20% of granular impurities, chiefly quartz, acid feldspar, and muscovite. Some glass or amorphous silica is present as well as a small amount of limonite.

Two general kinds of clay material occur in the sections. One appears to be montmorillonite and consists of abundant minute flakes arranged roughly parallel to the lamination of the clay. The other type is more coarsely crystalline and forms patches, streaks, and irregular areas haphazardly distributed through the clay. This material appears to consist of a mixture of allophane, halloysite and kaolinite. These same minerals are probably present in considerable amount mixed with the fine-textured montmorillonite. However, the nature of the mixture does not make feasible accurate estimation of the amounts of different clay-mineral constituents.

The coarsely crystalline material gave the following indices: $\alpha = 1.519 \pm .003$, $\gamma = 1.543 \pm .003$, birefringence .024. It is not certain that this coarsely crystalline material, which exhibits undulose extinction, is homogeneous. Index determination of the finer material was unsatisfactory, the indices lying within the range given for the coarser material.

With respect to structural habit, the montmorillonite shows three types of material. The first two appear to correspond to different laminae and to be responsible for the lamination.

The first type forms the major portion of the sections. It consists of granular or flaky montmorillonite containing about 20% impurities, chiefly quartz, with some acid feldspar and muscovite. The average grain size, for both the clay mineral and impurities, is about .03 mm. This material resembles that of Riverside (1). It shows little tendency to orientation.

In the second type certain laminae in the clay consist of montmorillonite of the oriented-shred variety, showing fair to excellent orientation, parallel to the lamination. This material is considerably purer than the granular montmorillonite. It is extremely fine, the average grain size

being about .01 mm. An estimated 5% maximum of impurities, all too fine to be identified definitely in sections is present, presumably of the same types as in the coarser material.

The third type of material resembles that of the Luce deposit. Patches of coarsely crystalline montmorillonite (?) in anhedral units or aggregate patches several millimeters in diameter occur in the sections. Single units showing undulose extinction may be as large as 1–2 mm. in length. These areas usually exhibit no relation to the lamination. In places they appear to follow cracks in the other types of material. The clay has been micro-faulted or brecciated, and the patches of relatively coarse montmorillonite (?) seem to be related in distribution to this disturbed condition.

The general structure of the clay is intermediate between the oriented-shred type and the granular type of Riverside (1). Traces of original ash structure are lacking, the material appearing to represent a sedimentary deposit. It appears that the material is too highly altered to clay to determine its origin with any degree of certainty. The presence of an interbedded ash exhibiting vitroclastic ghost structure in thin section, lends some slight support to a theory of bentonitic origin in part. However, the problem of origin is connected with the stratigraphic conditions of Tertiary time in Texas, and its solution seems to depend upon further detailed stratigraphic and microscopic work.

X-ray diffraction patterns of the clay material indicate the presence of montmorillonite, kaolinite, and quartz. From this and optical study, it is believed that montmorillonite, kaolinite, and halloysite are the principal clay mineral constituents with minor amounts of allophane.

FAYETTE DEPOSITS

The Fayette clays include five deposits situated in Fayette County;^{23,24} (1) the Carr-Brown tract, 9.4 miles northwest of Flatonia; (2) the Parker-Ivy tract, 9 miles north of Flatonia; (3) the J. A. K. tract, 1.5 miles north of Muldoon; (4) the Fleck-Darby tract, 3.5 miles north of Muldoon and 1 mile west of Lena; and (5) the Lena deposit of the Texas Company at Lena (Fig. 12).

The deposits are aligned along the general northeast strike of the Tertiary formations of the area.²⁵ They are all Eocene in age, occurring in the Jackson group.²⁶ The general dip is southeast, but for the most part the beds appear to be flat-lying. There is a slight structural disturbance as indicated by minor faults, which are particularly evident in the Fayette (1) property.

The clays in these deposits prove on field examination to represent essentially two types of material. One is typical bentonite, which is yel-

lowish and has a somewhat granular texture. The other is a somewhat waxy, chocolate-colored shale inclined to be more sandy than the bentonite. The sandy, chocolate-colored clays appear to be more widely distributed and to occur in thicker deposits than the yellow bentonitic clays. One would infer from field examination alone that the chocolate-

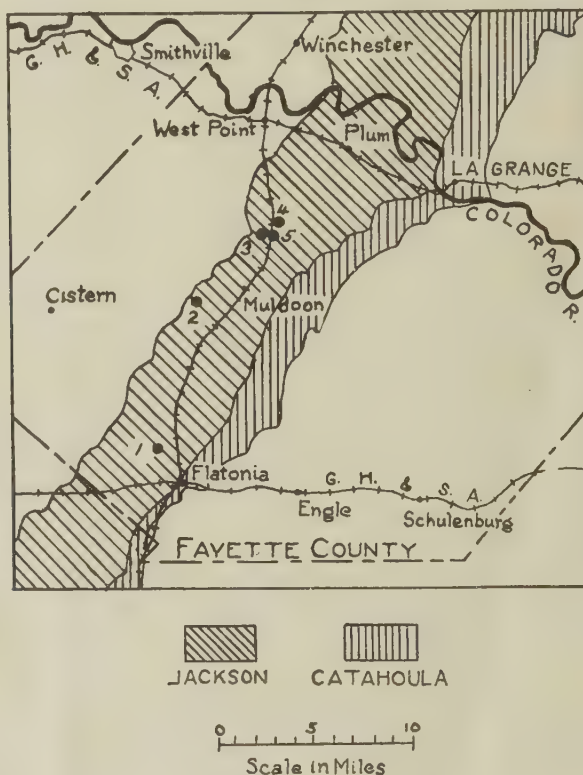


FIG. 12. Position of Fayette clay deposits on the geologic map of Texas. (See reference 1)

colored material is usually an ordinary sedimentary shale, while, on the other hand, it would seem more likely that the yellow clays are bentonites.

In the field, sandy ash beds several feet in thickness may be traced along small branches until they grade into bentonite. This is possible in several different places and it is assumed from this situation that the clays of the area were formed in localized alteration zones. It would appear that local geologic conditions are responsible for the alteration of the type observed. This situation is also suggested by the lack of uni-

formity of the alteration in certain places. In some of the beds, changes in texture and character of the clay may be observed within a few feet laterally and are even more apparent in vertical variations.

In several of the deposits opalized wood may be found in the strata immediately overlying the bentonite. The significance of this is not established, although it apparently indicates that if the clays were accumulated under marine conditions, they represent shallow water or near shore deposits. Marine fossils have been reported in the area discussed.

Another feature worthy of mention is the occurrence of gypsum in a number of places; this may indicate the action of sulphuric acid on the clay. It is not unlikely that the associated shale, which in some places contains abundant organic matter, could have supplied sulphur in such form that it would be readily converted to sulphuric acid. The action of this acid might easily account for the alteration of volcanic ash to bentonite. Unequal distribution of either the zones of solution, or the materials yielding sulphuric acid might explain the irregularity in distribution of the deposits.

The deposits exhibit similar mineralogic and petrographic characteristics. In all cases the clay-mineral constituent is montmorillonite,^{27,28} which forms most of the material in the thin sections examined. The principal impurities are quartz, feldspar, muscovite, and in some cases glass. A variable but small amount of undetermined organic matter is present in all the sections. The texture is fine, and the orientation poorly developed except in the cases of Fayette (4) and Fayette (5), where it is good. Examination of the x-ray diffraction patterns from the deposits furnishes a check on the identification of montmorillonite as the clay-mineral constituent.

Fayette (1) and Fayette (2)—The clay bed at (1) is about 3 feet in thickness, the best exposures occurring along a small branch. The clay is waxy, yellowish, and rather uniform in character. It has the appearance in hand specimen of a slightly gritty bentonite. Judging from the operator's information concerning the results of drilling, there is a considerable area of "bentonite" underlying the property (Fig. 13).

The clay bed is cut off by faulting along the branch, but neither the total displacement of the clay, nor the effect of faulting on the overburden, was apparent on brief investigation.

The clay exposures along a small branch of (2) comprise the following section: sandy ash, containing opalized wood, overlying the clay beds, 3 feet of impure yellow bentonite above a 4-inch bed of chocolate-colored bentonite, a one-inch layer of yellow waxy bentonite, and 18 inches of chocolate-colored shaly material (Fig. 14).

In thin section the material from (1) and (2) consists of 90 to 95% of montmorillonite. The indices of refraction show an extreme variation,



FIG. 13. Photograph showing clay bed faulted against sandstone and shale.



FIG. 14. Photograph of upper clay bed stripped for mining.

presumably dependent upon the water content of the clay. The indices on air dried clay from Fayette (1) are: $\alpha = 1.477 \pm .003$, and $\gamma = 1.499 \pm .003$, birefringence .022. The indices on Fayette (2) are: $\alpha = 1.462 \pm .003$,

and $\gamma = 1.483$, birefringence .021, $-2V$ small. These figures are as accurate as could be determined at present without standardizing the conditions of humidity under which the optical determinations were carried out. Impurities in (1) range from 5 to 10% whereas in (2) they represent only 2 or 3% of the material. In both deposits the chief impurities are feldspar, quartz, and muscovite. Chlorite, opal (diatoms), glass or amorphous silica, and limonite are present in varying but minor amounts.

The clay from (1) and (2) is fine-textured, the average particle size being .01 to .05 mm. Impurities are usually somewhat coarser. Orientation of the clay particles is either poor or lacking.

The material in thin section possesses a fine but poorly-developed bedding. Indefinite traces of vitroclastic structure are observable, and as these clays are similar to the bentonitic Fayette clays, it is believed that any definite evidence of original ash which might have been present was virtually obliterated by the extent of alteration. Associated with both deposits are fine ash beds exhibiting vitroclastic structure. The presence of diatoms and sponge (?) spicules suggests that the clays were deposited in lake or near-shore marine water.

X-ray diffraction patterns of (1) and (2) indicate that the clay mineral is montmorillonite.

Fayette (3)—The main bed at the J.A.K. tract is about 5 feet in thickness. The deposit has been opened and mined in a number of places, and probably contains the purest clay in the district. Material from this bed consists of a dense, pale, creamy yellow clay, apparently structureless in hand specimen.

Thin-section examination shows the material to consist of 50 to 60% montmorillonite. The indices of refraction of the montmorillonite are: $\alpha = 1.467 \pm .003$, $\gamma = 1.488 \pm .003$, birefringence .021, $-2V$ small. The remainder of the material is made up essentially of unaltered glass (30 to 40%), quartz, chlorite, feldspar, muscovite, and an occasional diatom.

The material is fine-textured, the average clay particle size being about .01 to .05 mm.; impurities are somewhat coarser. Orientation of the clay particles is poor or lacking, and when present is variable in character. The clay is finely, though indistinctly bedded and shows a well-preserved vitroclastic structure, indicating derivation from volcanic ash.

Some of the same material consists of 90 to 95% montmorillonite, the remainder being glass and sandy impurities. In this the vitroclastic structure has been almost completely destroyed, owing to the thoroughness of alteration. Thus, the extent of alteration varies from place to place in the same deposit.

Fayette (4)—Exposures of bentonite occur along a small branch about one mile west of Lena. The Fleck-Darby outcrops are covered with top soil and about 4 or 5 feet of a sandy, weathered, ash-like material. The bentonite bed appears to be impure, and is a little more than 4 feet in thickness. The upper portion consists of 3 feet of impure yellowish to yellow bentonite, a 4-inch chocolate-brown bentonite occurs near the bottom of the bed, and on the bottom there is a one-inch layer of bright yellow bentonite. Underlying the bentonite bed is an 18-inch layer of



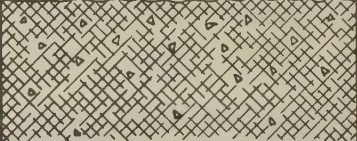

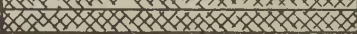

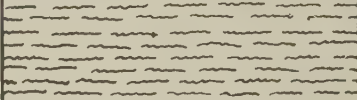

Description	Strata	Thickness
Soil		
Sandy weathered ash-like material with opalized wood.		
Impure Bentonite		2'
Yellow Bentonite		1'
Choc. bentonite		4"
Yellow benton.		1"
Chocolate shaly layer		1½'
Sand		

FIG. 15. Generalized section at the Fayette (4) deposit.

chocolate-colored sandy ash which appears to be stained bentonitic material (Fig. 15).

Opalized wood occurs in the sandy material over the bentonite, and it is thought that the dark stain of the bentonitic layer may be due in part to the presence of organic matter. While this deposit may be too variable to be of great interest from the economic standpoint, it provides an interesting sequence of materials.

Material from the chocolate-colored clay bed and from the chocolate-

colored sandy ash was examined in thin section. The clay bed contains about 70% montmorillonite, 25% unaltered glass, and about 5% granular impurities, chiefly quartz with some muscovite, opal (diatoms), doubtful glauconite, magnetite, and limonite.

The material is fine-textured, clay particles ranging from .01 to .05 mm. in size. The material exhibits good orientation of the clay particles, is well-bedded and rather uniform in character. It represents an ash with preserved vitroclastic structure. It is probable that the original ash was deposited in lake or near-shore marine water, as suggested by the presence of numerous diatoms and sponge (?) spicules.

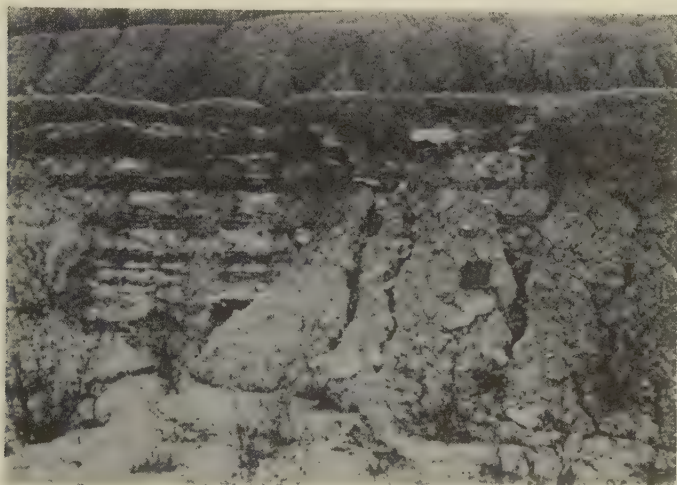


FIG. 16. Exposure in the old workings at Fayette (5) showing intercalated shaly and sandy strata. The loose slabs near the notebook are gypsum.

The chocolate-colored sandy ash contains approximately 80% montmorillonite. In comparison with the first sample, this shows a greater alteration to clay, and a higher percentage of the sandy impurities.

Fayette (5)—The most striking feature of the Lena deposit is the intercalation of impure clay with sandy layers, the outcrops of clay in the quarry resembling mixtures of sand and shale rather than the sequence one normally expects in a bentonite deposit. The best clay is a light chocolate brown, finely laminated material with occasional fine white streaks of sand (Fig. 16). A kaolin from the general vicinity of Lena has been described by Alexander Deussen.²⁹

In thin section this material shows considerable contrast to the other Fayette County clays. Judging from *x*-ray patterns and determinations

of optical properties, the clay mineral which forms an estimated 90 to 95% of the thin sections is montmorillonite. The indices of refraction show considerable variations, but fall within the range of published indices for montmorillonite. The values are $n=1.500$ mean index, birefringence .02, elongation positive, $-2V$ small. The impurities vary in amount and consist of quartz, muscovite, acid feldspar, opal (diatoms), chlorite, glass or amorphous silica, gypsum and limonite. It should be noted, however, that the percentage of impurities estimated from thin sections is undoubtedly low for the clay bed as a whole, since the material sectioned was free from the streaks of sand ordinarily present in hand specimen.

The texture is fine, the average clay particle size being under .1 mm. The fine texture and variability makes estimation of the amount of impurities uncertain.

The clay particles are well oriented and exhibit a well-developed lamination. Structurally, the clay is a borderline case between the oriented and oriented-shred types of montmorillonite, but is much closer to the latter, it being always possible to pick out the shreds which are the units of structure.

No indication of volcanic ash structure was observed in the specimen described. From field and microscopic study, this appears to be an ordinary sedimentary clay. It is possible that the absence of any indication of ash structure is due to completeness of alteration, but the presence of numerous diatoms suggests near-shore marine deposition, and the presence of numerous shreds of muscovite suggests at least considerable contamination by sedimentary material. Concentration of quartz in fine streaks parallel to the bedding is also strongly suggestive of ordinary sedimentary deposition. Nevertheless it is possible that in part the clay represents a highly altered and contaminated water-deposited ash. Associated interbedded strata, when not too highly altered, prove to be ash with well-preserved vitroclastic structures. The material from this deposit described by Broughton²¹ was probably selected from one or more of these bentonitic layers, as it does not agree petrographically or by x-ray examination with the material examined in this work.

GONZALES DEPOSITS

The Gonzales clays consist of three deposits situated in Gonzales^{23,26} and Karnes counties. Gonzales (1) and (2) were being operated by Coen and Company in 1936, and are located in Gonzales County. Deposit (1) is located about 6 miles from the town of Gonzales, and (2) is about 10 miles southeast of Gonzales. Gonzales (3) is located about $\frac{1}{2}$ mile

north of Gillett in Karnes County. All three deposits are in strata mapped as belonging to the Jackson group of Eocene age (Fig. 17).

In hand specimens the clays appear waxy and either yellow or chocolate-brown. In thin section the principal mineral constituent is montmorillonite, with quartz and feldspar the chief impurities. The material is fine-textured, poorly-oriented, and indistinctly bedded. The general

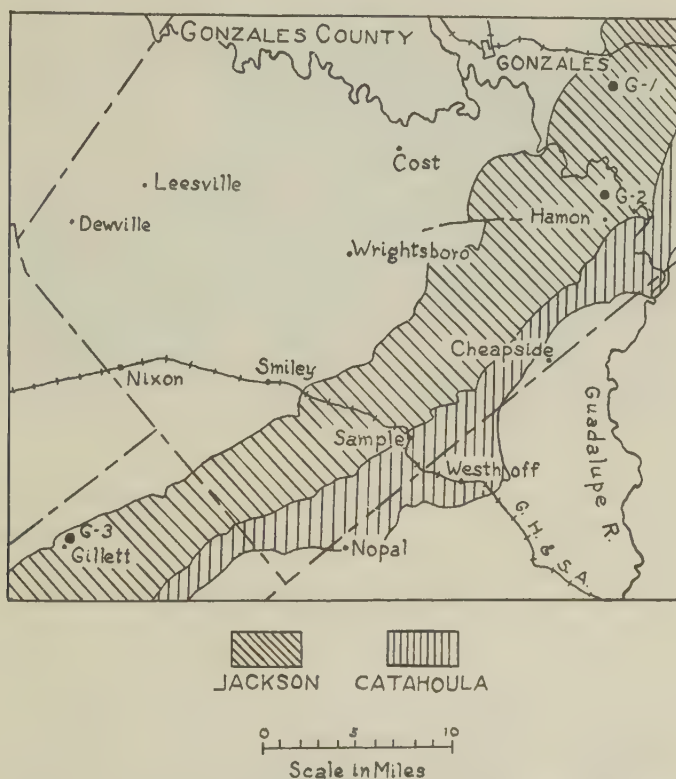


FIG. 17. Position of Gonzales clay deposits on the geologic map of Texas. (See reference 1)

structural aspect of the clays is bentonitic, but no definite evidence of volcanic origin is present in the sections.

Gonzales (1), (2), and (3)—Two different types of clay were being mined at (1). One is yellow, somewhat waxy, and has the appearance of a bentonite. This clay has a thickness of 2 to 3 feet, and occurs just beneath the soil overburden, which varies from 0 to 10 feet in thickness. The other is a variable layer of chocolate-colored clay which occurs be-

low the yellow clay, and is about 5 feet thick. This bed furnished most of the clay in former operations. Fossil wood occurs in the soil cap above the "bentonite," and large pieces of vegetable matter are present, replaced by gypsum.

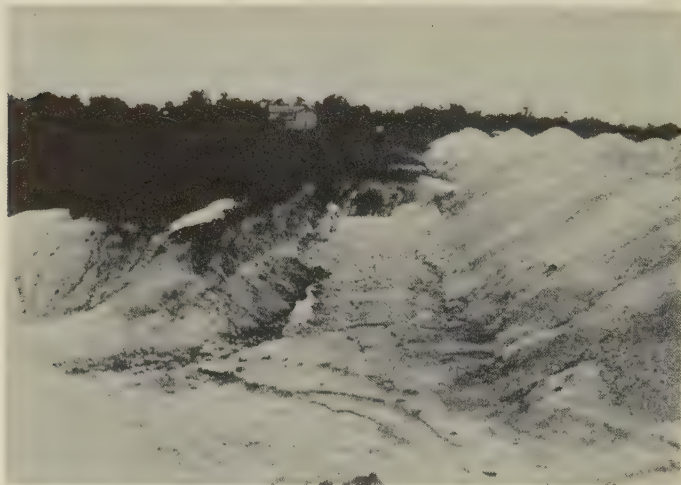


FIG. 18. Clay exposed in the open pit at Gonzales (2).


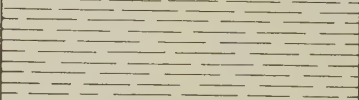



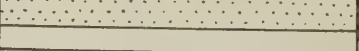
Description.	Strata	Thickness
Soil		10"
Chocolate Shale		5'
Broken Bentonite		2'
Ash		18"
Waxy bentonite		12"
Sandstone		3'

FIG. 19. Generalized section at the Gonzales (2) deposit.

The clay at (2) is about $3\frac{1}{2}$ feet thick and shows similar variation in color to (1), ranging from chocolate-colored clay to waxy yellow "bentonite." The clay is overlain by a chocolate-colored ash about 18 inches in thickness (Figs. 18 and 19).

The clay bed at (3) is about $5\frac{1}{2}$ feet thick. It consists of a hard chocolate-colored clay resembling bentonite in appearance. Above the clay stratum is an 18-inch layer of ash.

Microscopic examination shows that montmorillonite constitutes 80 to 85% of these three clays. Indices of refraction of (1) are: $\alpha = 1.462 \pm .005$, $\gamma = 1.482 \pm .005$, birefringence .02. Refractive indices of (3) are: $\alpha = 1.468 \pm .004$, $\gamma = 1.493 \pm .004$, birefringence .024. In addition to montmorillonite, halloysite (?) occurs in streaks in the fine-textured montmorillonite matrix.

An isotropic substance making up approximately 15 to 20% of the area of the sections examined is distributed through the clay. Grit, chiefly quartz and feldspar, forms from 1 to 5% of the material. Minor amounts of muscovite, diatoms, glauconite, and limonite are present.

The clay is fine-textured, the average particle size being about .01 to .03 mm. Orientation of clay particles is poor or lacking. A peculiar system of lenticular fractures is developed in (1) when it dries. Along these fractures there is some tendency to orientation of the clay material.

The sections exhibit an indistinct bedding. No definite evidence of either sedimentary or volcanic origin is present, it probably having been destroyed by alteration. The general appearance of the clay and closely associated beds which exhibit vitroclastic ghost structures, is suggestive of volcanic origin. The presence of glauconite, diatoms, and muscovite indicate contamination by sedimentary material and possible deposition of ash in water.

SUMMARY OF X-RAY DATA

X-ray diffraction study was carried out with a powder camera^{30,31} using molybdenum radiation. The width of arc was increased, yielding measurements of lines with large spacings. Numerous patterns were taken of clays from the various deposits described, and measurements of montmorillonite from selected samples were compared with those given by montmorillonite from Montmorillon, France, and from other localities. Measurements of the main clay at Luce, which is representative of the montmorillonite studied, are given in Table 1. Similar data by Gruner,³² Hofmann, Endell, and Wilm,³³ and Nagelschmidt³⁴ are listed for comparison.

TABLE 1. X-RAY DIFFRACTION MEASUREMENTS OF MONTMORILLONITE IN Å

Gruner ³²		Hofmann, Endell and Wilm. ³³		Nagelschmidt ³⁴		Hagner Mont., Fr.		Hagner Luce, Tex.	
A.U.	Int.	A.U.	Int.	A.U.	Int.	A.U.	Int.	A.U.	Int.
15.0	8	15.2	s	15.3	vs	15.3	s	15.3	s
		7.36	w			7.37	vw	7.37	w
						6.01	vw?		
		5.05	w	5.15	s	5.16	vw	5.07	vw
4.45	3	4.32	m	4.50	vs	4.43	m	4.51	vs
						3.86	w?		
						3.38	w?		
		3.13	vw?	3.07	vs	3.09	w	3.07	w
2.81	?			2.61	vs				
2.535	2			2.55	vs				
2.43	?			2.41	w				
						2.340	s	2.345	vs
2.228	0.5	2.205	m	2.240	vw			2.239	vw
		2.197	vw	2.155	vw				
1.851	0.5			1.905	vw				
				1.708	m				
1.688	1	1.661	w	1.682	vs	1.690	s	1.676	s
1.643	1								
1.494	3	1.470	m	1.497	vs	1.496	s	1.496	vs
1.415	0.5								
1.285	1	1.273	w	1.292	m	1.287	m	1.287	s
1.241	0.5	1.225	w	1.247	m	1.240	m	1.240	m
		1.110	vw						
		1.021	vw					1.023	vw
		0.966	w	0.970	vw	0.975	w	0.972	w
		0.862	w	0.863	vw				

A.U.—Interplaner spacing in Ångstrom units.

Int.—Intensity

vs—very strong, s—strong, m—medium, w—weak, vw—very weak.

MINERALOGICAL FEATURES AND ADSORPTIVE CAPACITY

ADSORPTION IN CLAYS

Adsorption has been defined by Robinson as depending upon "the change in interfacial tension produced by the presence of a dissolved substance in the liquid phase."³⁵ Many theories have been advanced in an effort to explain the mechanics of adsorption. Among the factors given as controlling adsorptive power are particle size, surface character, atomic structure, chemical composition, mineral composition, and a number of other physical and chemical factors mentioned below.

Evidence has been presented by Kelley³⁶ and others^{37,38,39,40,41} to the effect that, other things remaining the same, the smaller the particle size,⁴² the greater the adsorptive capacity.^{43,44} Opinions are on record⁴⁵ suggesting that adsorption is a surface phenomenon.^{46,47} Nutting has stated that "Clay particles (or oil sand grains) are potential bleaching agents for oil when their surfaces hold H or OH radicles adsorbed in a thin layer. When these are driven off by heating, open bonds are left which select from oil the darker, more basic constituents."⁴⁸ Flocculation,^{49,50} adhesion tension,^{51,52} porosity and density,⁵³ colloidal activity,^{54,55} degree of saturation of the complex,^{56,57,58,59} sesquioxide ratios,^{44,60,61} bases present^{62,63,64,65,66} and the effect of grinding,^{67,68,50} appear to be most emphasized as physical and chemical factors influencing adsorption. Recent studies by Marshall,⁶⁹ Nagelschmidt,^{34,70} Edelman,⁷¹ Neulen,⁷² Bragg,⁷³ Searle,⁷⁴ and others,^{75,76} indicate by *x*-ray analysis that minerals possessing a loosely bound layer lattice built up of silicon-oxygen tetrahedra, have more adsorptive power than those which do not possess such a structure.^{32,77} In general, clays with highest adsorptive capacity have certain similarities in chemical composition,^{78,45b} principally a relatively high percentage of removable bases and water. The clay mineral montmorillonite, in certain occurrences, is the most highly adsorptive of the clay minerals.^{79,80,81,82}

The Texas clays studied contain montmorillonite as the chief mineral and provide an unusual opportunity for observing a variety of physical occurrences of this mineral. The reason for variation in adsorptive capacity of montmorillonite in different occurrences is a matter of considerable interest, and of no little economic importance. It is hoped that the correlation of physical, chemical, and optical data of numerous montmorillonite-bearing Texas clays will contribute to the solution of this problem. It is felt that a somewhat detailed analysis is necessary if a correlation of important characteristics with adsorptive capacity is to follow. Where data on the Texas clays are insufficient, supplementary, physical, chemical and efficiency observations on other similar and important clays are substituted.

GRANULAR IMPURITIES

The unavoidable presence of small granular mineral impurities in the clays studied is believed to be one of the most significant features in connection with correlation of physical properties with adsorptive efficiency. Quartz, feldspar, and muscovite are the most abundant impurities, and are irregularly distributed in part in sandy streaks, and in part as disseminated grains in the purer clay. Because of the erratic distribu-

tion of these impurities, it is difficult to arrive at an accurate estimate of their average amount in any given clay bed as a whole, but they are judged to range from 2 to 25% in the deposits used for correlation of physical and chemical factors with efficiency.

Observations on impurities in the various clays indicate that adsorptive power increases with freedom from impurities. This may be shown for example by the relative efficiencies of two clays from Midway,⁴³ Florida. Midway 1 represents a purified fuller's earth in which particular care was taken to remove as much sand as possible before submitting it to efficiency tests. The efficiency rating of this clay is approximately eight points higher than that of Midway 1a, the same clay as Midway 1 but not purified. Commercial practice supports this conclusion. As far as bleaching power of clays is concerned, it seems that granular impurities largely represent inert matter (Table 2).

TABLE 2. IMPURITIES IN CLAYS STUDIED

Clay	Estimate % Impurities	Most Abundant Impurities
Polkville, Miss.	3	Quartz, feldspar, limonite.
Chambers, Ariz.	2- 3	Quartz, biotite, calcite, pyrolusite, glass.
Attapulgis, Ga.	5	Quartz, acid feldspar, muscovite, calcite.
Midway, Fla.	5-15	Quartz, acid feldspar, muscovite
Zavalla (1), Tex.	25	Quartz, feldspar, muscovite, kaolinite, glass or amorphous silica.
Luce, Tex.	25	Quartz, glass=20%.
Tehachapi, Calif.	20-25	Quartz, feldspar, biotite, zeolite and glass=20%.

Estimates include only principal kinds of impurities and are based upon samples of clays suitable for economic use.

CLOSELY BOUND IMPURITIES

In addition to granular impurities, clays often contain more tightly held, or difficultly separable, impurities such as zeolites, glass, or opal. From the standpoint of bleaching efficiency, kaolinite, allophane, and probably the halloysite present in certain northeastern Texas clays, might also be considered difficultly separable impurities. The effect of kaolinitic material on efficiency is taken up in the section on mineral composition. From the results listed in Table 2 it is inferred that zeolitic material and glass, or amorphous silica, possess little adsorptive power. This has been demonstrated by Nutting and others.

In both active and activable clays, closely bound impurities appear to affect the efficiency. The highest grade of activable clays, such as those from Chambers,^{43, 83} Arizona, and Polkville,⁸⁴ Mississippi are, on the

whole, remarkably free from difficulty separable material. Among the naturally active clays, Midway,⁴³ Florida and Attapulgus, Georgia,^{85,86} appear also to have greater freedom from such contamination. The latter, however, in virtually all commercial samples, contain fine inseparable material. This is not great in the case of the naturally active Zavalla (1) and Luce clays from Texas, or the naturally active clay from Tehachapi,⁸⁷ California.

As already stated, certain minerals^{79,80,81,88} have adsorptive powers in much higher degree than others. Of the clay minerals, montmorillonite,⁸⁹ beidellite,^{69c} and possibly halloysite^{69a,71a,45b} are strongly adsorptive, whereas kaolinite^{80,90} usually possesses little adsorptive capacity.

The Polkville, Mississippi, and Chambers, Arizona clays which possess high adsorptive power are relatively free from impurities and contain no kaolinitic material. On the other hand, the Zavalla (1) clay has a low efficiency rating, and contains chiefly kaolinite as the clay-mineral constituent. (See Table 5.) On the whole, the more kaolinitic clays of eastern Texas are generally admitted by producers to be less efficient than comparable naturally active montmorillonite clays of Georgia and Florida.

OPTICAL CONSTANTS OF ADSORPTIVE CLAYS

Optical constants of montmorillonite in the Texas clays may be compared with optical data derived from other montmorillonite clays. While there is some variation in the values for raw clays, they are in reasonably close agreement within the limits of error for the method used. Although no two samples yield exactly the same indices, most of them gave values within the same range. An exception is the montmorillonite from Zavalla (1), values for which are somewhat high compared with the others; this is probably due to the intimate manner in which it is mixed with kaolinitic material (Table 3).

The effect of activation on optical constants is to decrease refractive index values. It is believed that this may be due principally to acid treatment causing loss in weight per cent of MgO. Correns and Mehmel⁹¹ have shown that there is a uniform loss in refractive index with loss in weight per cent of MgO. Experiments by Mehmel⁹² indicate that loss of water results in an increase in refractive index up to 450°C. at which temperature refractive index values decrease. Similar results have been obtained on the clays studied. More recent dehydration tests carried out by Kelley⁶⁶ lead him to believe that the large losses in water content, due to loss of adsorbed water, occur at 180°C.; the other large losses that take place around 450°C. are believed to be due to loss of water in the crystal lattice.

TABLE 3. OPTICAL DATA

Clay	RAW			ACTIVATED		
	Ref. Index	Op. Angle	Biref.	Ref. Index	Op. Angle	Biref.
Polkville, Miss.	$\gamma = 1.512$	(-) sm.	.02	$\alpha = 1.476$ $\gamma = 1.502$	(-) sm.	.026
Chambers, Ariz.	$\gamma = 1.495$	(-) sm.	.02	$\alpha = 1.472$ $\gamma = 1.492$	(-) sm.	.02
Attapulcus, Ga.	$\alpha = 1.511$ $\gamma = 1.532$	(-) sm.	.021	$\alpha = 1.498$ $\gamma = 1.521$	(-) sm.	.023
Midway, Fla.	$\alpha = 1.508$ $\gamma = 1.529$	(-) sm.	.021	$\alpha = 1.500$ $\gamma = 1.520$	(-) sm.	.020
Zavalla (1), Tex.						
Kaolinite	$n = 1.565$ } mean		.005	not determined		
Halloysite	$n = 1.542$ } index		.003-4	not determined		
Montmoril.	$\gamma = 1.536$	(-) sm.	.02	$\gamma = 1.530$	(-) sm.	.02
Luce, Tex.						
Halloysite	$\gamma = 1.555$ max.; variable	(-) sm.		not determined		
Montmoril.	$\alpha = 1.490$ $\gamma = 1.512$	(-) sm.	.022	not determined		
Tehachapi, Calif.	$\gamma = 1.506$	(-) sm.	.02	$\gamma = 1.487$	(-) sm.	.02

All values $\pm .003$. Elongation positive. Extinction slightly inclined to cleavage.

In the clays studied the activated clay samples probably resorbed most or all of their water before index determinations were made. This may be seen in the chemical analyses made before and after activation (Table 4).

MICROSCOPIC STRUCTURES AND TEXTURES

Judging from the deposits studied, adsorptive efficiency varies regardless of microscopic structure and texture.⁴³ Lamination in the different deposits is variable, ranging from indistinct to well-developed. Orientation of clay particles and impurities ranges from clays having none to those with good orientation parallel to the bedding. The oriented shred-structure present in some clays and described as being due to packing, was at first believed to have some bearing on efficiency. However, no

essential relationship could be found between degree of development of this structure and relative efficiency of clay.

X-RAY DATA

X-ray diffraction patterns of material from the Texas clays were compared with other adsorptive clays of good quality. The patterns, together with petrographic and chemical data, confirm determinations of montmorillonite as the essential clay mineral constituent of the deposits studied.

Variations in amount of impurities, and presence of kaolinitic material are indicated by *x*-ray study. However, microscopic structures and textures appear to cause no significant differences in the patterns of montmorillonite.

X-ray diffraction patterns of activated clays, compared with those given by raw clays, indicate that activation causes no apparent change in the number or spacings of lines when ordinary molybdenum radiation is used. The diffraction lines are somewhat less clearly defined in patterns of activated clays, probably due to breaking up of particles during treatment.

These results would indicate that changes due to activation do not disturb the fundamental lattice structure. However, molybdenum radiation is inadequate to indicate small lattice changes. In view of the drastic chemical treatment during activation, and the fact that changes in water content^{93,33,70b,94} and isomorphous replacements⁷⁵ have been suggested by *x*-ray studies with copper radiation, it seems likely that some changes take place within the lattice, and probably also in the bonds between layers.

ALTERATION AND ORIGIN

The adsorptive quality of an individual clay mineral may be considerably affected by the amount and degree of alteration. Progress of alteration depends chiefly upon kind of original material and the agents of alteration. "The crystalline inactive kaolin minerals appear to be the product of extreme weathering of many kinds of igneous rocks and are highly stable. The bleaching clays appear to be composed chiefly of the less stable and less completely weathered clay minerals. . . . Many or possibly all of the bleaching clays would go over to kaolins if sufficiently leached and given sufficient time to take on water of constitution. A few clays have been thus transformed (from bleaching to china clay) in the laboratory by water treatment alone."^{45b} In general, however, the more original material left associated with clay, the less the efficiency. There-

fore, in the case of bleaching clay, alteration of original material to clay should be rather complete, but not so extreme as to form kaolin. This is believed to be true of the deposits studied.

Clays from Attapulgis, Georgia, and Midway, Florida, consist of a mineral of the montmorillonite group believed to have formed as a weathering product of crystalline rocks and then transported and deposited in shallow water. These deposits are part of a widespread group of fuller's earths occurring in Georgia and Florida. Alteration has been rather extensive and complete, producing good quality naturally active clays.

The geologic occurrence of the Polkville, Mississippi montmorillonite has been described briefly by Bay,⁸⁴ who called attention to its good quality and efficiency on activation. The clay bed has since been opened and mined. The clay is believed to have originated by alteration in place of almost pure volcanic ash. Alteration has progressed so far that the original ash structure has been largely destroyed. The close similarity of the clay to other bentonite deposits in the vicinity is most suggestive of bentonitic origin. The presence of glauconite and marine fossils in associated strata, together with the composition and general character of the beds, suggests that the clay was deposited in near-shore marine water.

An interesting feature of the Polkville clay is the virtual absence of detrital material so characteristic of the Georgia-Florida clays. It is believed that this absence may be traced directly to differences in origin. Since it is believed that the Georgia-Florida clays represent sedimentary accumulation, detrital material is expectable. On the other hand, impurities in the Polkville clay would be derived either from the original ash, or from adjacent rocks by solution. As a result, impurities consist essentially of iron oxide stain, glass remnants, and occasional grains of quartz and feldspar. The Polkville clay, due perhaps, in large part to its origin and the completeness of alteration, is a very pure activable clay.

The presence of unaltered ash in the vicinity of the clay supports the belief that the Chambers^{83,43} montmorillonite is probably bentonitic in origin. Any vitroclastic structure originally present has been destroyed by the high degree of alteration. The extent of alteration and small percentage of impurities has resulted in a good quality, highly activable clay.

The Zavalla (1) clay appears to represent a normal sedimentary deposit. However, it may be that alteration has obscured traces of original ash structure. The montmorillonite may be the result of alteration of volcanic ash, while the kaolinite, halloysite, and granular impurities represent sedimentary accumulation. This sedimentary material is be-

lieved to be largely responsible for the comparatively low efficiency of the clay.

The Luce clay represents volcanic ash now partly altered to a mineral of the montmorillonite group. In spite of alteration the structure of the original ash is clearly preserved. The halloysite present apparently reflects sedimentary contamination. This clay has a higher efficiency rating than Zavalla (1), probably because of a smaller percentage of sedimentary clay minerals and granular impurities. Also, the sedimentary clay mineral halloysite which is present, is said^{69a,71a} to have greater adsorptive capacity than kaolinite, which is present in considerable amount in the Zavalla (1) deposit.

The Tehachapi⁸⁷ montmorillonite originated by alteration of a volcanic ash bed. Although the deposit is quite extensive, the clay does not compare in purity with Chambers or Polkville fuller's earths. This is believed to be due to insufficient alteration, leaving a considerable amount of residual ash and zeolitic material.

Thus, the amount and degree of alteration is presumably of importance in connection with the decolorizing efficiency of clay. It appears, from data available, that completely altered bentonite forms the best activable clay. At any rate, clays resulting from rather complete decomposition of volcanic ash appear to have superior qualities for acid treatment.^{45b} Naturally active clays, on the other hand, may be less altered or less pure. Sedimentation evidently plays an important role in the origin of these clays in a number of instances, but not in all.

CHEMICAL COMPOSITION

Correlations of chemical composition with efficiency on the basis of a limited number of analyses are largely suggestive. However, the analyses in Table 4 indicate that the clays studied have a relatively high magnesia and water content.⁷⁸ Nutting has pointed out that bleaching clays "are characterized by high contents of loosely held water and by partial solubility in dilute ordinary acids, such as hydrochloric or sulphuric acid. The water is largely adsorbed water and is removable by heating to 200°C. . . . On the other hand, inactive clays, such as kaolin, retain almost all their water up to a red heat (500°C.). . . . Moderate dehydration to 200°C. is sufficient to develop the full bleaching power of the active clays, but heating to 600°C.-800°C. destroys that power; hence we infer that it is the water driven off between 50° and 200°C. that must be present in bleaching clays and must be driven off to induce bleaching power. Acid treated clays require similar heat treatment. . . . Before dehydration the kaolin minerals do not adsorb water or bleach oil, nor can

TABLE 4. CHEMICAL ANALYSES OF CLAYS STUDIED
(*Analyst*—Earl Emendorfer)

	Polkville, Miss.		Chambers, Ariz.		Attapulugus, Ga.		Midway, Fla.		Zavalla (1) Tex.		Luce, Tex.		Tehachapi, Calif.	
	Raw	Ac- tivated	Raw	Ac- tivated	Raw	Ac- tivated	Raw	Ac- tivated	Raw	Ac- tivated	Raw	Ac- tivated	Raw	Ac- tivated
SiO ₂	49.59	58.66	50.03	55.70	53.42	63.46	52.92	64.73	60.21	66.50	52.53	59.81	58.95	71.07
TiO ₂	1.11	.40	.84	.33	.52	.46	1.18	.49	.69	.60	.31	.33	.74	.20
Al ₂ O ₃	15.07	16.15	15.00	13.13	10.06	8.65	9.41	8.18	21.33	17.04	22.86	19.01	9.92	8.38
Fe ₂ O ₃	1.93	1.03	2.79	2.28	3.40	3.16	3.35	3.21	2.36	2.70	1.51	1.62	2.03	1.45
FeO	.09	.06	.13	.16	.18	.18	.30	.30	.20	.17	.11	.11	.26	.23
MnO	.01	.01	.01	.01	.02	.02	.03	.02	.01	.01	.04	.03	.01	.01
MgO	4.83	4.19	4.53	3.45	9.16	6.39	9.05	5.62	1.16	.81	2.16	1.27	4.64	2.22
CaO	1.39	.22	2.60	.31	1.29	.21	1.91	.41	.66	.15	1.30	.26	1.09	.52
Na ₂ O	.02	.05	.08	.12	.02	.02	.03	.02	.16	.13	.05	.13	.19	.43
K ₂ O	.15	.05	.12	.13	.64	.68	.98	1.00	1.13	1.12	.05	.31	.46	.60
P ₂ O ₅	.03	.05	.02	.05	.12	.33	1.21	.46	.10	.05	.04	.04	.03	.04
H ₂ O above 110°C.	8.10	8.83	8.29	7.47	9.42	9.18	10.19	8.90	7.85	7.30	8.04	7.93	7.11	7.14
H ₂ O at 110°C.	17.76	9.48	15.63	15.77	11.83	6.78	9.06	6.05	3.75	2.69	10.98	8.35	14.28	7.19
CO ₂	.01	none	.02	.01	.05	none	.11	none	.05	none	.04	none	.02	none
Cl	.02	.02	.01	.01	.03	.02	.02	.02	.03	.36	.03	.03	.01	.02
SO ₃	.02	.79	.04	.72	.02	.19	.04	.26	.03	.02	.02	.59	.02	.60
Sum	100.13	99.99	100.14	99.65	100.18	99.73	99.79	99.67	99.72	99.73	100.07	99.82	99.76	100.10

Activated clays were acid treated and heated to 550°F.

they be activated by acid treatment."^{45b} Somewhat similar dehydration data have been published by Mehmehl⁹² and Kelley.⁶⁶

Analyses of naturally active commercial earths from Attapulugus and Midway show relatively high lime, magnesia, and water, relatively low alumina, and a moderate amount of ferric oxide. Variations in the silica content are believed to reflect differences in degree of purity, rather than any essential difference in composition of the clay mineral. The percentages of other minor constituents show irregular variation, and are not considered to have any significant bearing on the problem of bleaching efficiency. The Midway clay is somewhat lower in alumina than the clay from Attapulugus, a difference which is not unusual in the montmorillonite group and may be attributed to isomorphism.

It is interesting to note that the activable Polkville and Chambers clays contain less magnesia, and a slightly higher alumina and water content than the Georgia-Florida clays. The inactivable Tehachapi clay contains less magnesia and slightly more lime than the Georgia-Florida clays, but agrees with them more closely in chemical composition than with the Polkville or Chambers clays.

The active Zavalla (1) and Luce clays show a higher alumina content and a lower magnesia, lime, and water content than any of the other clays studied. These differences in chemical composition presumably reflect the presence of kaolinitic material. Zavalla (1) also has a relatively high amount of potash, probably due to an appreciable percentage of muscovite.

Analyses of activated clays show a considerable increase in silica with a corresponding decrease, in most cases, of alumina, magnesia, lime, ferric oxide, and water at 110°C. The decrease, with the exception of Chambers, in water at 110°C. may be due to drying. This contrast is perhaps overemphasized in the table, since sufficient activated material was not available to permit the degree of purification that was possible with raw clays. Increase in sulphuric anhydride may be attributed to the acid used. Other small changes may be detected, and it is possible that acid treatment produces a structural change in clay which is evidently not great, as little change in diffraction lines is observable in an x -ray study, using molybdenum radiation.

In making the above comparisons it has been kept in mind that the clays analyzed, even after purification, were unavoidably contaminated with finely divided impurities. Reasonable allowance for the compositions and amounts of impurities has been made in the comparisons cited above.

SUMMARY

Many rocks and minerals possess adsorptive capacity in some degree, or can be made adsorptive by treatment with acid.^{45b} However, most of these substances are of no practical value in refining oils, the commercial adsorbents being composed principally of the mineral montmorillonite. Recently bauxite⁹⁵ has been used successfully for oil decolorization, and under certain conditions is even more efficient than other commercial adsorbents, thus giving promise of its further use for this purpose.

Why some clays are naturally active and others neither naturally active or activable is a problem of considerable importance. At present little is known about these phenomena because of insufficient available standardized efficiency ratings. Also, "the ratings of active minerals according to their bleaching efficiency is obviously a quite arbitrary matter, because the relative bleaching power of any series of clays will be different for every test liquid used. . . . Even with a specific clay and test oil there is the question of which cut to choose as standard. . . ." ^{45b}

It has been suggested that the silica of active clays is more soluble than that of inactive clays. Also, that certain fuller's earths improve in efficiency with acid treatment "due to the removal of limonite, calcite, and possible hydrous alumina which may exert a clogging effect on the active minerals."⁶⁴ In the clays studied, with the exception of Attapulgius, little or no calcite or other carbonate was present in thin sections. The amount of limonite present was virtually negligible, occurring largely or entirely as surface stain. In Table 5 it may be seen that activable clays have a somewhat lower silica content than the naturally active clays. This is probably due to a greater freedom from impurities

TABLE 5. EFFICIENCY DATA

Clay	Decolorizing Efficiency*	Type
Polkville, Miss.	115.0	activable
Chambers, Ariz.	120.0	activable
Attapulgius, Ga.	30.0	naturally active
Midway, Fla.	33.0	naturally active
Zavalla (1), Tex.	60.0	naturally active
Luce, Tex.	95.0	naturally active
Tehachapi, Calif.	38.0	naturally active

After treating for 6 hours with 34 wt. % of 100% sulphuric acid (basis volatile free clay) in 8% solution.

* Commercial tests of acid treated clays based upon a standard acid treated clay = 100%. Temperature 550°F., 20 minutes with steam.

containing appreciable silica. In any estimate of the significance of silica it should be kept in mind that small amounts of opal dispersed through montmorillonite may frequently escape detection.

Summarizing the data presented in this study it seems possible to offer the following suggestions in regard to correlation of mineralogical characteristics with adsorptive capacity. The presence of granular or inseparable impurities lowers the adsorptive capacity of a given clay. Strongly adsorptive members of the montmorillonite group possess an abundance of loosely held water. If any connection exists between microscopic structures, or textures, and adsorptive capacity it is yet to be established. X-ray data indicate that clay minerals with the montmorillonite lattice have a structure which permits a high degree of adsorption. The amount and degree of alteration of original material to clay appears to be related to adsorptive capacity. Montmorillonite clay reasonably free from coarse or closely held impurities while not normally active, may be activated to a high degree. Correlation between origin and adsorptive capacity appears either limited or doubtful, except that adsorptive clays originating by transportation of material tend to contain more granular impurities than those altering in place from volcanic ash, and seem to be active but poorly activable. High percentages of removable bases as well as water presumably accompany high adsorptive capacity. Montmorillonite appears to be the most highly adsorptive clay mineral.

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COMPOSITION, SPACE GROUP AND UNIT CELL OF HANKSITE

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ABSTRACT

The composition of $9\text{Na}_2\text{SO}_4 \cdot 2\text{Na}_2\text{CO}_3 \cdot \text{KCl}$ for hanksite is verified. There are 2 formula weights in the hexagonal unit cell, which has $a = 10.46\text{\AA}$ and $c = 21.18\text{\AA}$; $c/a = 2.02$. The space group is either $C_6^3 - (C6_3)$ or $C_{6h}^2 - (C6_3/m)$, with the morphological evidence indicating the latter. It is suggested that hanksite may have a superstructure, based on 12 unit cells of Na_2SO_4 I.

The composition of hanksite was originally reported¹ as $4\text{Na}_2\text{SO}_4 \cdot \text{Na}_2\text{CO}_3$, with KCl (or NaCl) present as an impurity. It was later shown² that an error had been made in the original calculation, and that the ratio of sulfate to carbonate was 9:2. Moreover, the constant percentage of KCl present indicated that this constituent was an essential part of the composition. The resulting formula, $9\text{Na}_2\text{SO}_4 \cdot 2\text{Na}_2\text{CO}_3 \cdot \text{KCl}$ is in general use, and the only reason for again raising the question as to the composition of hanksite is that Schulten³ described microscopic crystals of artificial hanksite, which he obtained from a solution containing Na_2SO_4 and Na_2CO_3 , with no KCl present. It is obvious that if hanksite can be prepared from a KCl-free solution, KCl cannot be an essential constituent.

Schulten's method is based on the reduced solubility of Na_2SO_4 and Na_2CO_3 in water when NaOH is added. The author has followed the detailed instructions given by Schulten, and has secured material which agrees perfectly with that described by him. Schulten's identification of the material as hanksite was based upon a chemical analysis, and upon approximate measurements of interfacial angles with the microscope. His crystals were about 0.05 by 0.03 mm. in size.

The compound $2\text{Na}_2\text{SO}_4 \cdot \text{Na}_2\text{CO}_3$, corresponding to the mineral burkeite, can be easily prepared by the slow evaporation of hot solutions of Na_2SO_4 and Na_2CO_3 in water.⁴ It has been shown⁵ that there is extensive solid solution of both Na_2SO_4 and Na_2CO_3 in $2\text{Na}_2\text{SO}_4 \cdot \text{Na}_2\text{CO}_3$. The range of compositions is reported as varying from $3\text{Na}_2\text{SO}_4 \cdot \text{Na}_2\text{CO}_3$ to $\text{Na}_2\text{SO}_4 \cdot \text{Na}_2\text{CO}_3$. It would seem evident that Schulten's material be-

¹ Hidden, W. E., *Am. Jour. Sci.*, **30**, 133-5, 1885; Dana, E. S., and Penfield, S. L., *ibid.*, 136-7.

² Pratt, J. H., *Am. Jour. Sci.*, **152**, 133-5, 1896.

³ Schulten, M. A. de, *Compt. Rend.*, **123**, 1325-7, 1896.

⁴ Ramsdell, L. S., *Am. Mineral.*, **22**, 213, 1937.

⁵ Schroeder, W. C., Berk, A. A., Partridge, E. P., and Gabriel, A., *Jour. Am. Chem. Soc.*, **58**, 846, 1936.

longs in this solid solution series, with an even higher ratio of sulfate to carbonate, namely, 4:1. The solution which Schulten used had a ratio of sulfate to carbonate of about 8:1, and the crystals precipitated from this solution happened to have approximately a 4:1 ratio, thus seeming to agree with the supposed composition of hanksite.

Schulten described his crystals as hexagonal, with the basal section usually showing a division into six sectors. This agrees with the pseudo-hexagonal penetration twins observed on synthetic burkeite.⁴

A conclusive proof as to the identity of Schulten's material can be obtained by *x*-ray methods. A powder photograph of crystals prepared according to his instructions, and agreeing with his description, shows that they are not hanksite, but rather material belonging to the Na_2SO_4 - Na_2CO_3 solid solution series. They differ from burkeite in having a higher percentage of Na_2SO_4 . It thus seems apparent that Schulten did not obtain hanksite crystals from a KCl-free solution.

Positive evidence as to the essential character of the KCl content in hanksite is available from two sources. In the first place, the number of formula weights in the unit cell can be calculated, using the density, unit cell volume, and the weight of one molecule. The result is 2.1 formula weights per unit cell, if the composition is assumed to be $9\text{Na}_2\text{SO}_4 \cdot 2\text{Na}_2\text{CO}_3$, whereas the number is 2.002 when the composition of $9\text{Na}_2\text{SO}_4 \cdot 2\text{Na}_2\text{CO}_3 \cdot \text{KCl}$ is used. Since the number of formula weights should be an integer, the latter result is more plausible. This can be stated in another way. Assuming the number of formula weights per unit cell to be 2, the calculated density for the 9:2 formula is 2.45, and that for the 9:2:1 formula is 2.57. The latter agrees closely with the density of the natural crystals, which is 2.56.

Further evidence as to the essential role of the KCl is found in the behavior of hanksite when heated. If clear fragments of hanksite, appearing homogeneous under the microscope, are fused and cooled, the resulting material consists of a clear groundmass containing microscopic blebs and stringers. Actual fusion is not necessary. Heating to a temperature slightly below the melting point causes hanksite to separate into the two phases. The *x*-ray diffraction pattern of the main phase no longer corresponds to that of hanksite, but is identical to that obtained when Na_2SO_4 and Na_2CO_3 are fused together in the proportion of 9:2. No positive identification of the minor phase has been made, but it appears that upon heating above a certain temperature, hanksite is no longer stable, and decomposes, forming $9\text{Na}_2\text{SO}_4 \cdot 2\text{Na}_2\text{CO}_3 + \text{KCl}$. The KCl forms less than 5 per cent by weight of the total, and does not show in the powder photographs. The blebs and stringers have an index above that of the ground mass, which agrees with the respective indices for KCl and the Na_2SO_4 - Na_2CO_3 fusion.

Comparable results are obtained from melts. If Na_2SO_4 and Na_2CO_3 in the 9:2 ratio are fused together, the product is homogeneous. If KCl be added, corresponding to the 9:2:1 ratio, the blebs and stringers appear. Thus hanksite cannot be synthesized from a melt of the 9:2:1 composition, because it is unstable at the temperature of the melt. The $9\text{Na}_2\text{SO}_4 \cdot 2\text{Na}_2\text{CO}_3$ formed by the decomposition of hanksite does not represent a definite compound, but is a member of a solid solution series which will be described later in this paper.

X-RAY DATA

Unit cell. Accurate measurements from high order reflections on Weissenberg films, and from powder photographs standardized with KCl, give the values $a = 10.46\text{\AA}$ and $c = 21.18\text{\AA}$. These agree closely with those reported by Gossner and Koch.⁶ The axial ratio, $c/a = 2.02$, is almost exactly twice that given for the natural crystals, namely, 1.0056. From the cell volume and density, it is found that the unit cell contains $18\text{Na}_2\text{SO}_4 \cdot 4\text{Na}_2\text{CO}_3 \cdot 2\text{KCl}$.

Symmetry. Laue photographs taken with the x -ray beam parallel to the c axis show a 6-fold axis, with no vertical planes of symmetry. Photographs taken parallel to the a and the intermediate b axes likewise show no vertical planes, but a horizontal plane of symmetry is present. This corresponds to the symmetry of the hexagonal bipyramidal class, C_{6h} . However, since a Laue photograph indicates a center of symmetry, whether present or not, both the trigonal bipyramidal, C_{3h} , and the hexagonal pyramidal, C_6 , classes are possibilities, for when a center of symmetry is added to either of these, C_{6h} is obtained.

Space group. In none of these three symmetry classes is a rhombohedral unit cell possible, so there is no choice to be made between rhombohedral and hexagonal units. In symmetry class C_{3h} there is only one space group, characterized by a normal rotation axis. C_6 has six space groups, as follows: one with a normal rotation axis; an enantiomorphous pair characterized by screw axes with translations of $\frac{1}{3}$ and $\frac{2}{3}$, respectively; a second enantiomorphous pair with translations of $\frac{1}{6}$ and $\frac{5}{6}$; and a final space group having a screw axis with a translation of $\frac{1}{2}$. The C_{6h} class has only two space groups, one with a normal rotation axis, and one with a screw axis with a translation of $\frac{1}{2}$.

Comparison of 0-level and n -level Weissenberg photographs, taken with either the a or b axes as rotation axes, shows that the translations are doubled on the reciprocal lattice line through the origin and parallel to c . This indicates a screw axis with a translation of $\frac{1}{2}$. This immediately eliminates the one space group of C_{3h} , five of the space groups of C_6 ,

⁶ Gossner, B. and Koch, I. *Zeits. Krist.*, **80**, 461-4, 1931.

and one of C_{6h} , leaving only one space group in each of C_6 and C_{6h} as possibilities. These are $C_6^6-(C6_3)$ and $C_{6h}^2-(C6_3/m)$. X-ray methods can make no distinction between these two possibilities.

Attempts to obtain etch figures have been unsuccessful. Likewise, tests for pyro- and piezo-electricity have been negative. Therefore, the only remaining evidence lies in the morphology of the crystals. The lack of hemimorphic development suggests that the probable space group is $C_{6h}^2(C6_3/m)$, but this cannot be regarded as proved.

Possible structure. The unit cell of hanksite contains two molecules, which means that there are 44 Na, 18 SO_4 , 4 CO_3 and 2 KCl to be located. The largest number of equivalent points in the space group C_{6h}^2 is 12. These positions are defined by three variable parameters. Special positions of six and four equivalent points have two and one variable parameters, respectively. It would be almost hopeless to attempt a direct determination of such a structure. However, there is some indirect evidence as to a possible structure.

In order to explain this possibility, it must be pointed out that Na_2SO_4 exists in three crystalline modifications: I, the high temperature form, stable only above $241^\circ C.$; III, the intermediate form obtained by the inversion of I, and which, although metastable, can be kept at ordinary temperatures for indefinite periods; and V, the low temperature stable form. The high temperature form, I, can be stabilized by the addition of Na_2CO_3 .

It has been found⁵ by optical methods that melts of Na_2SO_4 and Na_2CO_3 are miscible in all proportions from 0 to 0.75 mole fraction of Na_2CO_3 . X-ray data confirm the existence of this solid solution series in the range from about 0.1 to 0.6 mole fraction of Na_2CO_3 . In this range, diffraction photographs are almost indistinguishable, indicating that CO_3 replaces SO_4 with very little change, either in structure or dimensions. Moreover, except for a slight decrease in spacing, such photographs give data agreeing very closely with those reported for Na_2SO_4 I, taken above $241^\circ C.$ ⁷ (Table 1). With less than 0.1 mole fraction of Na_2CO_3 , powder photographs indicate that Na_2SO_4 I inverts to III on cooling, but with more than 0.1, the high temperature form persists. Both optical and x-ray data indicate that this solid solution series is hexagonal, and it is dimorphous with the low temperature series, which is orthorhombic, pseudo-hexagonal, and includes synthetic burkeite and possibly Na_2SO_4 III.

⁷ Kracek, F. C. and Ksanda, C. J., Polymorphism of sodium sulfate. IV. X-ray analysis. *Jour. Phys. Chem.*, **34**, 1741-4, 1930.

TABLE 1. DIFFRACTION DATA FOR Na_2SO_4 I ABOVE 241° AND FOR THE HEXAGONAL $\text{Na}_2\text{SO}_4\text{-Na}_2\text{CO}_3$ SOLID SOLUTION

Na_2SO_4 I (Kracek and Ksanda) ⁷		$\text{Na}_2\text{SO}_4\text{-Na}_2\text{CO}_3$ 2:1	
Spacing	Intensity	Spacing	Intensity
4.684A	3	4.60A	2
3.917	10	3.85	9
3.616	6	3.55	7
2.863	9	2.80	10
2.699	9	2.66	10
2.348	2	2.30	1
2.213	2	2.18	5
1.961	7	1.92	9
1.814	2	1.77	5
1.583	2	1.56	4
1.555	3	1.53	2
1.503	4	1.47	4
1.427	1	1.40	1
1.348	2	1.33	3
1.27	2	1.25	1
1.21	2	1.20	2
1.18	2	1.17	1

As previously stated, when hanksite is heated above a critical temperature, it decomposes to form $9\text{Na}_2\text{SO}_4 \cdot 2\text{Na}_2\text{CO}_3$ and KCl. The diffraction pattern of this material corresponds to that of the high temperature hexagonal $\text{Na}_2\text{SO}_4\text{-Na}_2\text{CO}_3$ series. However, the pattern has marked resemblances to the original hanksite pattern. Most of the lines of the fused hanksite are also found in the normal hanksite pattern, with a slight decrease in spacing. But the hanksite pattern has additional lines, not appearing in the pattern of the $\text{Na}_2\text{SO}_4\text{-Na}_2\text{CO}_3$ series, which cause it to correspond to a different hexagonal unit. The axial ratio for the hanksite unit is 2.02, whereas the value of c/a for the $\text{Na}_2\text{SO}_4\text{-Na}_2\text{CO}_3$ series is about 1.34. The indices (hkl) of the reflecting planes of the normal and of fused hanksite have the relationship shown in Table 2. It will be noticed that for the lines common to both patterns, all values of h and k for fused hanksite are multiplied by 2, and those of l are multiplied by 3, to give the corresponding indices of normal hanksite. This indicates that the unit cell of hanksite has a c axis 3 times as long, and an a axis 2 times as long as those of the $\text{Na}_2\text{SO}_4\text{-Na}_2\text{CO}_3$ series, or of Na_2SO_4 I.

TABLE 2. PARTIAL POWDER PHOTOGRAPH DATA FOR HANKSITE AND THE HEXAGONAL $\text{Na}_2\text{SO}_4\text{-Na}_2\text{CO}_3$ SOLID SOLUTION

Hanksite 9:2:1		$\text{Na}_2\text{SO}_4\text{-Na}_2\text{CO}_3$ 9:2	
Spacing	Indices	Spacing	Indices
5.24A	11 $\bar{2}$ 0	—	—
4.58	20 $\bar{2}$ 0	4.60A	10 $\bar{1}$ 0
3.83	20 $\bar{2}$ 3	3.85	10 $\bar{1}$ 1
3.54	0006	3.55	0002
3.42	21 $\bar{3}$ 0	—	—
2.78	20 $\bar{2}$ 6	2.80	10 $\bar{1}$ 2
2.63	22 $\bar{4}$ 0	2.66	11 $\bar{2}$ 0
2.52	31 $\bar{4}$ 0	—	—
2.27	40 $\bar{4}$ 0	2.30	20 $\bar{2}$ 0
2.16	40 $\bar{4}$ 3	2.18	20 $\bar{2}$ 1
1.91	40 $\bar{4}$ 6	1.92	20 $\bar{2}$ 2
1.77	00012	1.78	0004

This relationship between the unit cells of hanksite, Na_2SO_4 I and the $\text{Na}_2\text{SO}_4\text{-Na}_2\text{CO}_3$ series, suggests that hanksite has a structure based upon $3 \times 2 \times 2 = 12$ smaller pseudo-cells, each corresponding to one unit cell of Na_2SO_4 . This latter cell contains 2 molecules of Na_2SO_4 , and 12 such cells would contain the equivalent of 24 molecules.

If the Na_2CO_3 and KCl content of hanksite were distributed statistically throughout the Na_2SO_4 , the true unit would be the Na_2SO_4 unit cell. This would seem to be the situation where only CO_3 replaces the SO_4 , as in the solid solution series. But if they occupy definite positions, the true unit must be larger. For example, there are only 2 molecules of KCl for every 18 of Na_2SO_4 , so the unit of repetition must be at least 9 times as large. The unit as actually determined contains $18\text{Na}_2\text{SO}_4 + 4\text{Na}_2\text{CO}_3 + 2\text{KCl}$, which gives a total of $24(\text{Na}_2\text{SO}_4, \text{Na}_2\text{CO}_3, \text{KCl})$, if the three different molecules are grouped together. Assuming that the Na_2SO_4 and Na_2CO_3 are mutually replaceable, then 2 out of every 24 molecules are KCl, and the unit of repetition must be 12 times as large as the simple Na_2SO_4 unit.

According to this interpretation, the hanksite structure would be described as a superstructure, based on 12 unit cells of Na_2SO_4 I, in which the KCl occupies a definite position. The conditions under which the KCl will assume this definite position are not known, but apparently the arrangement is not highly stable. Heating causes it to break down, and the structure degenerates into the simple Na_2SO_4 I type.

It should be pointed out that there is no proof as yet of the existence

of this superstructure, but in the absence of any direct determination of the structure, this conjecture offers a plausible explanation of the observed relationships between hanksite, Na_2SO_4 I, and the Na_2SO_4 - Na_2CO_3 series.

CLERICI SOLUTION FOR THE SPECIFIC GRAVITY DETERMINATION OF SMALL MINERAL GRAINS

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In the identification of minerals, as well as in the determination of their properties, modern methods tend to minimize the amount of material necessary for satisfactory results. In this direction lie the immersion methods of optical investigations and the more recently developed microchemical techniques. Certain cases, however, require the determination of hardness and specific gravity as an adjunct; of these the specific gravity is the more easily and accurately obtained.

Among the more common methods of gravity determination are: (a) the suspension, (b) the pycnometric, (c) the micropycnometric, and (d) the immersion methods. The pycnometric method is the most precise of the first three, although micropycnometry (1, 11, 14)* may attain nearly the same degree of accuracy with a considerable reduction in the amount of material required. These advantages also obtain in the case of immersion methods (in which the mineral grains are placed in a liquid medium and the specific gravity of the liquid varied as desired), and in addition the speed of manipulation is greatly increased. This simple technique has had limited application in the past, due to the paucity of liquids of high specific gravity, as well as to their excessive cost, chemical instability, or poisonous nature. The writer believes that most of these defects can be overcome by the use of Clerici solution (sp. gr. approx. 4.32 when saturated at room temperature) in very small quantities, as indicated in the following paragraphs.

PREPARATION AND PROPERTIES OF CLERICI SOLUTION

Strictly speaking, Clerici solution is a mixture of equal parts of thallium formate (HCOOTl) and thallium malonate ($\text{CH}_2(\text{COOTl})_2$), dissolved in a minimum amount of water. It is a mobile, odorless liquid, straw-yellow in color. The specific gravity of the saturated solution at 20°C . is $4.324 \pm .002$; this can be increased by heating and dissolving more of the salts to make a more concentrated saturated solution at the higher temperature (2), and decreased by dilution with water.

The solution used by the writer was prepared by dissolving 300 grams of each salt** in 40 cc. of water, warming slightly to hasten the process.

* Numbers in parentheses refer to references cited in the bibliography at the end of this paper.

** Thallium formate and thallium malonate are obtainable as dry salts from the Eastman Kodak Co., Rochester, New York. Prices quoted are \$7.00 per 100 grams for the former, \$9.00 per 100 grams for the latter.

The resulting solution is not saturated, but can be made so by careful evaporation (heating over a hot plate gives good results) to the point at which a yellow-brown, curdy hydrolysis product begins to form. Filtration gives about 135 cc. of clear, concentrated liquid, ready for use.

Concerning the use of Clerici solution, there are several important features to be considered. (a) Evaporation of water with resultant frac-

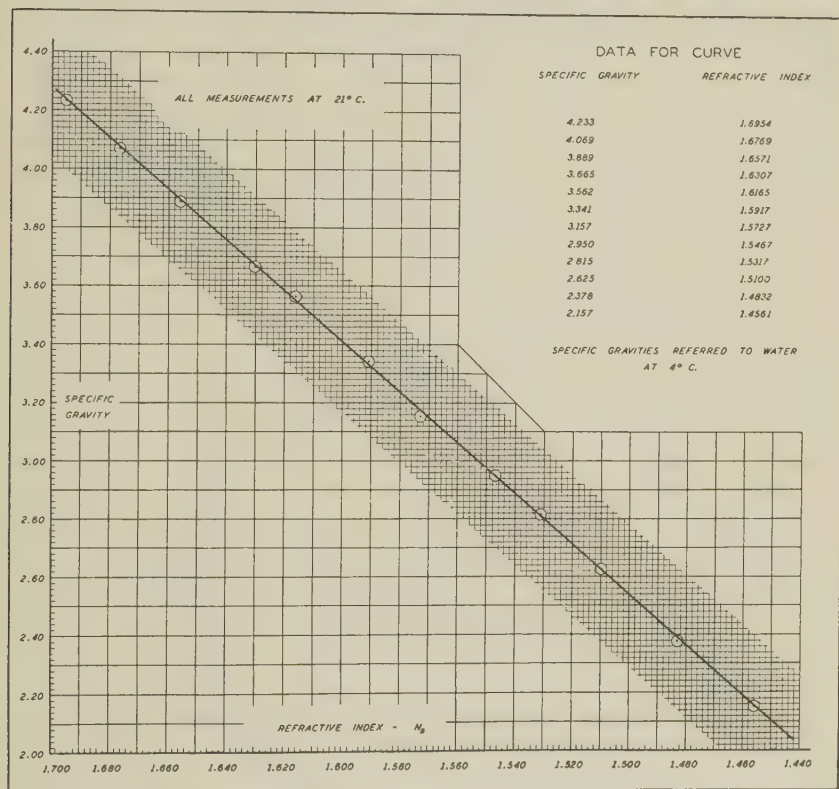


FIG. 1. Relation between specific gravity and refractive index of Clerici solution at 21°C.

tional crystallization of thallium malonate must be avoided. Because of the higher molecular weight of this salt, its loss from solution lowers the specific gravity and refractive index of the saturated liquid. (b) Although the solution appears to be stable and inert toward all water-insoluble minerals at ordinary temperatures, it may react with sulfides (12) or with magnetite (13) if exposed to them for long periods when hot. (c) Its extremely poisonous and corrosive nature necessitates careful handling. (d) The high cost of the solution is somewhat offset by the ease with which it can be recovered and reconcentrated. Careful water-washing of

all grains and receptacles, followed by evaporation of the washings gives at least 99% recovery of concentrated liquid.

As shown by Vassar (12), a straight-line relationship exists between the refractive index and specific gravity of Clerici solution. Because solutions made up of unequal parts of thallium formate and thallium malonate were used in previous index-gravity determinations (12), it was considered advisable to make a similar study of solutions containing equal parts of the two salts. Such solutions are most easily reproduced, now that the dry thallium salts are obtainable on the market. Specific

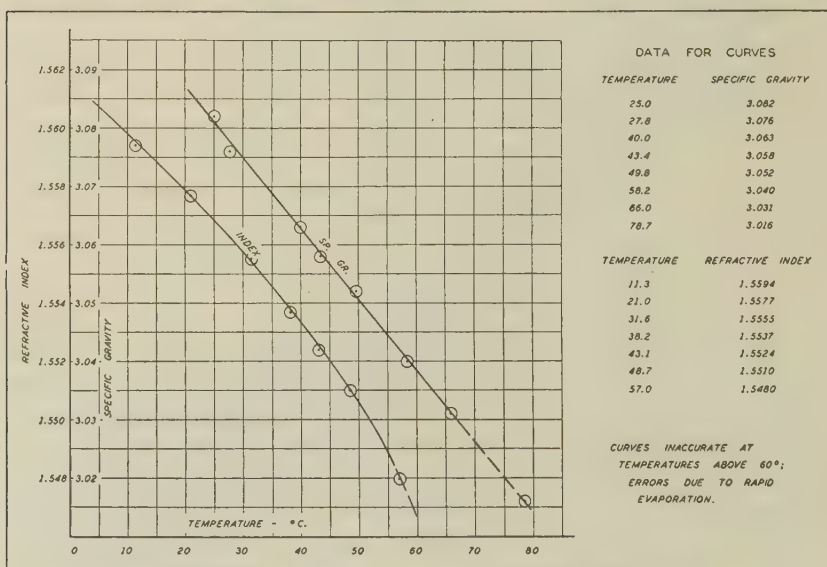


FIG. 2. Temperature-specific gravity and temperature-refractive index curves for a sample of moderately concentrated Clerici solution.

gravities at various concentrations were obtained with a Westphal balance at controlled temperature, and the corresponding refractive indices determined at the same temperature. In spite of changes due to evaporation, the results checked to within 0.01 g./cc. in specific gravity and 0.003 in index. Figure 1 shows the relations involved.

Two samples of specific gravity approximately 3.1 were tested for variation of index and gravity with temperature. Although the curves as plotted (Fig. 2) are approximations, they show the general relations and furnish the data for temperature variation constants:

$$\frac{dN}{dT} = -0.00025/\text{degree C.}$$

$$\frac{d \text{ sp. gr. }}{dT} = -0.0012 \text{ g./cc./degree C.}$$

Both these figures are constant for this concentration only, and will decrease with increased water-dilution.

SPECIFIC GRAVITY DETERMINATION OF MINERAL GRAINS

Because most rocks crushed to 80 to 200 mesh yield particles essentially monomineralic, the following method of gravity determination was developed particularly for use with such grains. It follows that a method applicable to individual grains so small (0.15 to 0.32 mm. in diameter) has the additional advantage of requiring minute amounts of material for positive results. In dealing with individual grains, more-

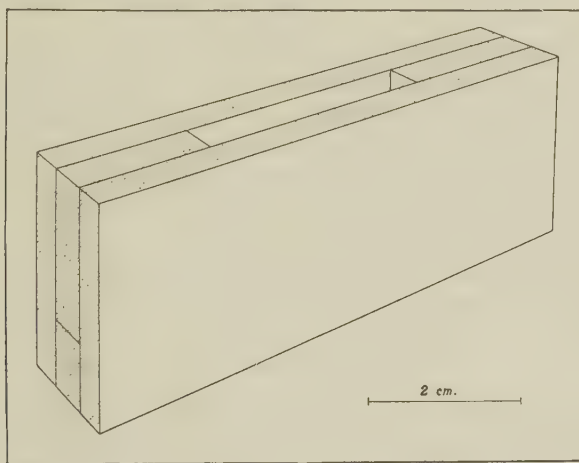


FIG. 3. Small glass settling tank used for the suspension of mineral grains in Clerici solution.

over, a preliminary inspection under the microscope is possible, in which pure grains of the desired identity and of optimum shape and size can be selected.

A small settling tank of about 0.5 cc. capacity must be constructed from glass plates, as shown in Fig. 3. Two ordinary glass microscope slides are held apart by strips of a third, thicker slide in the manner indicated; the pieces are cemented with a syrupy celluloid-acetone mixture. Celluloid strips may be substituted for the glass if desired. The tank is placed on the microscope stage, where it can be cemented lightly or held by the mechanical stage. The barrel and stage are tilted until the

microscope axis is horizontal; in this position the tank is correctly oriented for receiving the Clerici solution.

Into the liquid-filled tank is introduced the mineral grain to be tested. It may be handled with a camel-hair brush, with the helpful device designed by Howard (4), or by any of the methods suggested by Partidge (9). Once the grain is "wetted" and freed from air bubbles by agitation with a thin wire, its behavior in the liquid is easily noted through the low-power objective. When it floats in the concentrated solution, water is added drop by drop from a length of music wire until the grain remains suspended or nearly so. Thorough stirring is essential to obtain a homogeneous liquid.

Care must be taken, too, to prevent the microscope lamp from heating the solution in the tank to a point above standard temperature (about 21°C.). A flask filled with 0.5 *N* copper sulfate solution placed between the microscope and the lamp obviates this difficulty.

When the specific gravity of the liquid has been brought into correspondence with that of the grain, several drops are placed on the Abbe refractometer and their index quickly determined. This is converted into specific gravity by means of the curve in Fig. 1. Several tests have shown that this simple and rapid method gives results reliable to the nearest 0.01 in specific gravity. Additional refinements in the procedure would undoubtedly decrease this figure.

The Clerici solution should be checked from time to time with the Westphal balance or with standard mineral grains (7). Should there be a slight departure from the norm in specific gravity at any given concentration (due to fractional crystallization of thallium malonate or any other cause), the corresponding refractive index may be determined and a new point plotted on the grid of Fig. 1. Through this point a new curve may be drawn parallel to the standard curve, taking over the function of the latter in ensuing determinations. For very accurate work, a correction factor is necessary if the obtaining temperature is other than 21°C. A correction in gravity of +.001 per degree above 21° and -.001 per degree below 21° should be made.

Earlier investigators have constructed refractive index-specific gravity tables for Thoulet solution (potassium-mercuric iodide) (3) and for Rohrbach's solution (barium-mercuric iodide) (6). Because it is difficult to prepare and maintain in a standard condition, the former is not well suited for determinative work. Rohrbach's solution is more satisfactory, but requires a complex technique in handling. Further, it has a maximum density little greater than 3.55, and its refractive indices corresponding to gravities above 3.1 fall outside the range of the Abbe refractometer, which is the most convenient tool for index determination.

CONCLUSIONS

Clerici solution is considered one of the most desirable liquids for immersion methods of specific gravity determination because:

- (a) It combines great mobility, even at high concentrations, with a specific gravity greater than that of most other heavy liquids.
- (b) It is odorless and has no objectionable color.
- (c) It can be used at room temperature, and at such is inert and stable.
- (d) Its specific gravity is lowered by addition of water and raised by evaporation of the water. The latter feature makes for easy and efficient recovery of concentrated solution and somewhat offsets its high initial cost.
- (e) The relation between its specific gravity and its refractive index is a simple and constant one.

The method of specific gravity determination of individual grains in the manner outlined has certain outstanding advantages:

- (a) Individual grains, of very small size if necessary, can be selected and microscopically inspected before their gravity is obtained. This is particularly helpful where there is little material available.
- (b) The accuracy of this method compares favorably with that of the more laborious pycnometric method.
- (c) The time required for a determination is much less than that needed for similar material in other methods.

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INVESTIGATION OF A NEW OCCURRENCE OF ALURGITE FROM CALIFORNIA

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ABSTRACT

An occurrence of a purple mica is described, an analysis of the mineral presented, and the conclusion reached that it is identical with alurgite, described previously only from St. Marcel, Piedmont, Italy. It is contended that alurgite is sufficiently different in physical and optical properties to warrant retaining the name as a varietal name in the series of the mica group between muscovite and biotite.

INTRODUCTION

In the course of investigations of mineral localities of southern California, specimens of a copper- to purplish-red micaceous mineral were submitted to the writer by Mr. and Mrs. V. D. Myers of Santa Monica, California. Examination of the material shows it to be a rare variety belonging to the mica group, alurgite. As far as the writer is aware, this is the first occurrence of alurgite to be reported in North America.

PREVIOUS STUDIES OF ALURGITE

The only systematic description of alurgite was published by Penfield,¹ who investigated the properties of the rose-red mica from Piedmont, Italy, and showed it to be identical with the specimens examined and but briefly described by Breithaupt,² who named the mineral. Penfield's study is apparently the only systematic treatment ever published. In 1909, during a systematic study of the manganese deposits of India, Fermor³ reported four occurrences of red and pink mica, in various associations, which he groups "provisionally" under the heading "alurgite (?)." Regarding these occurrences, he writes (p. 199):

On comparing the pleochroism of these Indian rose and crimson micas with that of the alurgite from St. Marcel in Piedmont, it will be seen that although the pleochroism schemes are somewhat different, the colours corresponding to each elasticity axis have a general resemblance to one another. . . . It will also be noticed that the optic axial angles of the Indian micas bear a general resemblance to those of the St. Marcel mineral. . . . Hence these Indian micas can be provisionally regarded as alurgite, until they have been subjected to the test of analysis.

¹ Penfield, S. L., On some minerals from the manganese mines of St. Marcel, in Piedmont, Italy: *Am. Jour. Sci.*, **46**, (3rd Series) 288-295, 1893.

² Breithaupt, J. F. H., *Berg- und hüttenmännische Zeitung*, **24**, 336, 1865.

³ Fermor, L. Leigh, The manganese-ore deposits of India: *Memoirs Geol. Soc. India*, **37**, 1-1294, 1909.

Gennaro,⁴ in a brief preliminary note, records the occurrence of red mica in two localities in the Piedmont Alps. It is identified as alurgite on the basis of similarity to the St. Marcel, Piedmont, locality. Detailed petrographic descriptions of these occurrences were promised to appear in a later paper.⁵

LOCATION AND MODE OF OCCURRENCE

The alurgite is found in boulders in alluvium on the summit of the Cajon Pass, in western San Bernardino County, about twenty miles north of the city of San Bernardino, California. The first ravine west of the summit of Cajon Pass contains much of the material. The stream boulders are piedmontite-alurgite-quartz schists, and piedmontite-alurgite quartzites, scattered heterogeneously through the gravels of the desert. According to the map and sections of Noble,⁶ the boulders are found in gravels of Pliocene or Pleistocene age underlying the true Pleistocene alluvial deposits. The alurgite forms major foliation planes of the schist, with alternating bands of quartz. Microscopic examination of slides of the alurgite-bearing rock shows it to contain, in addition to those constituents seen megascopically, a few small needles of apatite, magnetite, and an occasional grain of zircon.

DESCRIPTION OF THE ALURGITE

The colors of alurgite given for the type locality in Piedmont are similar to those of the locality under discussion, being a copper-red to lavender-rose, with occasional shades of deeper red, or magenta. The deeper shades are due to minute included crystals of piedmontite which lie between the alurgite flakes. Nowhere were there observed the deep purple colors rarely shown at the Piedmont locality.

Other physical properties check those of the mica group. The cleavage is perfect pinacoidal, with the leaves somewhat less elastic than the commoner micas. The specific gravity, determined by F. A. Gonyer, Harvard University, is 2.914. The hardness is 2.5–3. Some specimens of alurgite show a fading of the color on weathering. In the determination of the indices of refraction, it was noted that in those flakes which have undergone considerable alteration, the values are somewhat lower than

⁴ Gennaro, Virginia, Micascisti a piemontite nelle valli di Lanzo (Alpi Piemontesi), Nota preliminare, presentata dal Socio Artini: *Rendiconti della R. Accademia Nazionale dei Lincei*, Classe di Scienze fisiche, matematiche e naturali, 2, serie 6^a, 2° sem., fasc. 11°, 1925 (Rome.)

⁵ The writer has been unable to discover additional references to this locality. It is thus inferred that additional data have not as yet been published.

⁶ Noble, Levi F., Excursions to the San Andreas fault and Cajon Pass: *Int. Geol. Cong. XVI, Guidebook 15*, Southern California, 10–21, pl. 3, 1932.

for the unaltered material. Also some iron oxide seems to have been liberated during alteration, as some of the alurgite flakes are surrounded by rims of hematite.

Blowpipe analysis of the alurgite, which was separated from the piedmontite under a lens before testing, showed a strong manganese color in the sodium carbonate bead. Tests with the borax bead failed to show a strong test for manganese, but gave only a very weak color. The reaction of alurgite to sodium carbonate and not to borax was mentioned by Penfield,⁷ who obtained a manganese test in borax only upon addition of much material. Furthermore, a pronounced test for iron in the borax bead was obvious, and it probably masked effectively the usual purple color of manganese.

Using oil immersion and basal sections of alurgite, the index of refraction was determined to be between 1.590 and 1.595, decidedly closer to 1.595. Larsen and Berman⁸ give 1.594 for gamma and beta. The alurgite is non-pleochroic in basal sections, and slightly pleochroic in pale flesh pink and orchid tints in sections normal to the cleavage.⁹ The alurgite is separated from manganophyllite, with which it might be confused, by less intense pleochroism, and lower indices of refraction. The color is pale flesh-pink in all unweathered grains; deep pink to brownish-red when alteration has set in. The optic angle is given in standard tables as from 0 to 57 degrees. The alurgite from this locality shows a pronounced biaxial figure. No determinations of 2V have been made, but from the perfect figures obtainable from almost any fresh grain, the angle can be estimated as at least 30 degrees. The optic sign is negative, as in all micas.

SUMMARY OF THE PROPERTIES OF ALURGITE FROM THE TWO LOCALITIES

	California	Italy
Color	lavender-rose	cochineal red
G.	2.914	2.835-2.849 (Penfield) 2.984-3.00 (Breithaupt)
Pleochroism	Pale flesh pink to orchid	Not marked: faint in shades of pink and red.

⁷ *Op. cit.*, p. 290.

⁸ Larsen, Esper S., and Berman, Harry. The Microscopic Determination of the Non-paque Minerals: *U. S. Geol. Surv., Bull.* **848**, 165, 1934.

⁹ The material examined by the writer showed an exceedingly pale flesh-pink pleochroism. H. Stanton Hill, of Pasadena Junior college, who obtained some alurgite during the completion of a study of the Pelona^{9a} schists, from a small outcrop on the Prairie Fork of the East Fork of the San Gabriel River, showed the writer a section in which the pleochroic color in sections normal to the cleavage was a distinct orchid. No orchid pleochroic colors and no pleochroic colors as intense as those from the outcrop, were observed on material from the Cajon Pass occurrence.

^{9a} Hershey, Oscar H., Some crystalline rocks of southern California: *Am. Geol.*, **29**, 273-290, 1902.

Indices of Refraction	α =not determined	$\alpha=1.55$
	$\beta=1.595$	$\beta=1.594$
	$\gamma=1.595$	$\gamma=1.594$ (Larsen & Berman)

ANALYSIS OF ALURGITE

Only one analysis of alurgite has been published up to the present. Following is the original analysis as given by Penfield,¹⁰ and the analysis of the material from the California locality.

	Alurgite* (Italy)	Alurgite** (California)
SiO ₂	53.22	46.30
TiO ₂	—	0.71
Al ₂ O ₃	21.19	28.52
Fe ₂ O ₃	1.22	5.32
FeO	none	none
Mn ₂ O ₃	0.87	—
MnO	0.18	0.65
MgO	6.02	4.27
CaO	—	0.14
K ₂ O	11.20	9.15
Na ₂ O	0.34	0.61
F	—	0.67
H ₂ O	5.75	—
H ₂ O—	—	0.03
H ₂ O+	—	4.08
		<hr/>
Less O		100.45
		<hr/>
Total	99.99	100.17

* S. F. Penfield, *Analyst*.

** F. A. Gonyer, *Analyst*.

The higher ferric iron content and absence of manganic oxide are noted in the California material in comparing the two analyses. The silica and alumina percentages seem to be insufficiently different to consider the mineral a different variety of the mica group. The SiO₂, Al₂O₃, K₂O, and MgO are present in percentages which, considering the wide variations shown within the mica group, fall well within the allowable range.

The absence of manganic oxide (Mn₂O₃) might suggest that the material was not alurgite since Penfield¹¹ suggests that:

It is probable that the deep red color of the mineral is due to the presence of Mn₂O₃, for it is well known that the higher oxides of manganese have intense coloring power . . .

The color of the alurgite from the California locality, however, is probably due to the presence of TiO₂.

¹⁰ *Op. cit.*, 290.

¹¹ *Op. cit.*, 291.

POSSIBLE IDENTITY OF ALURGITE AND MARIPOSITE, AND
RELATIONS TO OTHER MEMBERS OF THE MICA GROUP

In a discussion of analyses of mariposite and their relations to the analysis of alurgite from the Piedmont locality, Schaller¹² concludes that mariposite and alurgite are identical. This conclusion is not supported by the studies of Knopf¹³ on the important mariposite localities of the Mother Lode belt, who points out that Schaller's

... argument is not conclusive, as alurgite is a purple to cochineal-red mica. The mineral mariposite is evidently only of varietal rank; it is a green chromiferous sericite.

In discussing further the possible identity of mariposite and alurgite, Dr. Schaller says:¹⁴

The names alurgite and mariposite may have some justification as varietal names but certainly not as distinct species names.

A study of the analysis of alurgite from the new California locality seems definitely to establish the fact that the use of the name "alurgite" as anything but a varietal name is incorrect. The principal oxides of the mica group make up the bulk composition of alurgite. Since the members of this group form a continuous series of constantly changing composition, of which mariposite, alurgite, etc., are simply points on the composition curve, to place alurgite as a distinct species would be definitely incorrect. The statements of Knopf¹⁵ indicate that he misunderstood Schaller's concept of the identity of the two minerals (as did the writer prior to exchange of letters with Schaller), since Knopf recognizes mariposite as a variety of sericite and not as a separate mineral species.

The California occurrence was suspected of being identical with a purple muscovite described by Schaller and Henderson.¹⁶ Upon analysis, however, the MgO and Fe₂O₃ content of the California occurrence showed these to be distinctly different.¹⁷

¹² Schaller, Waldemar T., The probable identity of mariposite and alurgite: *U. S. Geol. Surv., Bull.* **610**, 139-140, 1916.

¹³ Knopf, Adolph, The mother lode system of California: *U. S. Geol. Surv., Prof. Paper* **157**, 38, 1929.

¹⁴ Personal communication, letter dated June 6, 1938.

¹⁵ *Op. cit.*

¹⁶ Schaller, Waldemar T., and Henderson, Edward P., Purple muscovite from New Mexico: *Am. Mineral.*, **11**, 5-16, 1926.

¹⁷ Dr Schaller, on the other hand, feels that the analysis of the alurgite from Cajon Pass is such that in spite of appreciable MgO and Fe₂O₃ content, it should be classed as muscovite, and not as a separate variety of the muscovite-biotite series. He says (by letter dated July 29, 1938):

"I question the correctness of calling your mica alurgite on the basis of Gonyer's analysis, although in appearance and color your mica is almost identical with the alurgite

SOURCE OF THE ALURGITE BOULDERS

Noble¹⁸ has shown in his studies along the San Andreas fault, in the vicinity of Cajon Pass, that the so-called Cajon "amphitheater" has been produced by the degradation of streams draining the southwestern slopes of the San Bernardino-San Gabriel Mountains. The base level of these streams is essentially the San Bernardino lowland; they have extended their drainage areas at the expense of northeastward flowing streams whose base level is the Mojave desert. The latter streams have thus been beheaded. They formerly drained the then much higher San Bernardino-San Gabriel mountains, during which time they deposited huge alluvial and piedmont alluvial fans at the northeastern bases of the mountains. (See topographic maps, U. S., Cucamonga, Hesperia, San Antonio, San Bernardino quadrangles.) Many of those rocks which were the source materials for the alluvial fans of the northeastern slopes have now been eroded away. Thus, when one constructs profiles from northeast to southwest up the slopes of the alluvial fans and onto the mountain ranges, the restoration of the piedmont alluvial slopes indicates that the source of material was at least 1500 feet above the present erosional level in the general area from which the material must have come. This figure is very conservative, since no allowance is made for the increasing concavity upward of the fan slopes adjacent to the mountain ranges.

It seems, therefore, that most of the source materials of the alurgite are probably eroded away, unless, of course, the roots of the layers of the alurgite schists and quartzites are still present in the broken and contorted zones of the Pelona schists present along the San Andreas fault.¹⁹

PROBABLE WIDER DISTRIBUTION OF ALURGITE BOULDERS

Several weeks after the samples of alurgite from the Cajon Pass locality were obtained, the writer, collecting some actinolite samples from gravels just south of the highway near Palmdale, California, along the from Italy. There is too great a discrepancy in the percentages of SiO_2 and R_2O_3 (chiefly Al_2O_3). . . . My own feeling is that any name other than muscovite for your mica would be open to criticism."

The writer feels, however, were alurgite to be classed by a species name rather than a varietal name, that the MgO and Fe_2O_3 content is such that the alurgite should be classed as biotite and not as muscovite. A varietal name seems desirable, however, since so many of the properties of this mica are distinct from normal muscovite.

¹⁸ *Op. cit.*

¹⁹ As mentioned above, Hill collected specimens of alurgite identical with the Cajon Pass material from a narrow outcrop on Prairie Fork of the East Fork of the San Gabriel river. From this and other exposures now eroded away, probably came the large quantity of boulders of the Cajon Pass occurrence.

San Andreas fault, picked up two or three small boulders of schists which were apparently the same as those found to the south in Cajon Pass. These boulders, more deeply weathered than those of the first locality, contained smaller quantities of the alurgite, although it is obvious upon comparing them that they came essentially from the same source. It is, therefore, highly probable, that the distribution of alurgite is not confined to these two localities, but that this mineral will be found elsewhere, at least along the San Andreas fault.²⁰

ACKNOWLEDGMENTS

The writer wishes to acknowledge assistance obtained in the identification of the mineral and from discussions preliminary to the preparation of the manuscript from the following: Dr. Joseph Murdoch, Assistant Professor of Geology, University of California, Los Angeles; Dr. W. T. Schaller, United States Geological Survey; Dr. A. O. Woodford, Professor of Geology, Pomona College, Claremont, California; and Mr. H. Stanton Hill, Instructor in Geology, Pasadena Junior College, Pasadena, California.

²⁰ Mr. Leland H. Dykes, of Los Angeles, California, informed the writer that he had seen material identical with the Cajon Pass occurrence which was collected near White-water, California, by the late Gordon A. Surr, formerly of the University of California Citrus Experiment Station at Riverside, California.

CRYSTALLOGRAPHY OF VEATCHITE

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ABSTRACT

Some terminated crystals of veatchite, the newly discovered borate from Lang, California, have been measured on the goniometer, the elements calculated, and fourteen forms observed. Using the published x-ray determination of the unit cell, the elements are:

$$\begin{array}{ll} a:b:c = 0.163:1:0.998 & \beta = 121^{\circ}02' \\ p_0:q_0:r_0 = 6.1227:0.8551:1 & \mu = 58^{\circ}58' \\ r_2:p_2:q_2 = 1.1694:7.1599:1 & \\ p_0' = 7.1455 & q_0^1 = 0.9980 \quad x_0' = 0.6017 \end{array}$$

The following forms are recorded, and an angle table calculated for them: $b(010)$, $f(014)$, $g(013)$, $h(023)$, $d(011)$, $j(043)$, $o(031)$, $l(310)$, $q(230)$, $n(120)$, $k(140)$, $t(160)$, $s(180)$, $p(\bar{1}66)$. In addition there are a number of other poorly developed prisms and domes, and one other possible pyramid.

The new calcium borate, veatchite, was described by Switzer,¹ but he gave no crystallographic data, owing to the lack of suitable material. His description reminded the writer to re-examine some material from Lang which had been given him some time ago. The specimen proved to have a considerable amount of veatchite, some of it in distinct crystals. The identification was confirmed by a close agreement of properties, the only important difference being the observed angle made by the secondary cleavage with the prism zone. Switzer reported this as $67^{\circ} (\pm 1)$,² but the writer determined it, both crystallographically and microscopically, to be slightly under 59° . The indices of refraction were in essential agreement, and the angle -38° , $Z:c$, was confirmed. Specific gravity, by Clerici solution ($2.58 \pm .01$), was slightly lower than Switzer's value. The luster is pearly on the perfect cleavage, and vitreous elsewhere, and cleavage flakes closely resemble gypsum.

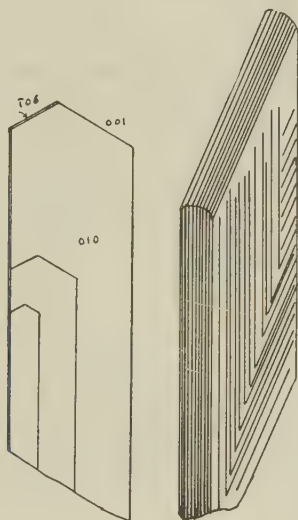
OCCURRENCE

The writer's material is contained in a single hand specimen which shows a vein of colemanite in shale. A visit to the locality, and careful search has so far failed to uncover any additional specimens. The colemanite is not solidly massive, but has many open spaces, with well developed crystal faces. In one instance a minute crystal of secondary colemanite was observed, perched on the surface of a larger crystal. The veatchite occurs entirely in the colemanite vein, growing in the spaces between the colemanite crystals. In some parts it is in "nests" of

¹ Switzer, George, Veatchite, a new calcium borate from Lang, California, *Am. Mineral*, **23**, 409-411, 1938.

² *Loc. cit.*, 409.

radiating plates, filling these spaces completely. In others, it does not take up the entire space, and occurs in part as terminated crystals. These crystals are quite varied in size and habit, ranging from capillary fibers one-fourth to nearly a centimeter in length, to broad flat plates one to five or six millimeters across, in the case of single crystals. In addition there are larger platy aggregates up to a centimeter or so in length and breadth. The more slender prismatic forms are usually single individuals, growing in tufted or radiating masses, often nearly parallel. The platy forms are more usually aggregates of several units, in essentially parallel position. Figure 1 shows one of these, of microscopic size,



FIGS. 1 AND 2. Crystal developments of Veatchite.

with its largest dimension under .5 mm. Here three crystals are grown together, showing the development of (010) terminated on top by the clinodome zone and a negative pyramid which lies in the $(\bar{1}06)$ zone. The bottom is truncated by the poorer cleavage. The prism zone is almost absent, but is shown under the microscope by the varying thickness of a very narrow edge of the crystal. Most of the larger crystals are tabular and similar but do not show the development of the pyramid.

In general, veatchite is later than the colemanite, and deposited on it. In one or two cases, however, veatchite crystals are partially or wholly enclosed by colemanite, indicating a closer age relationship, or possibly replacement of colemanite by veatchite, although the limited amount of material at hand does not permit a definite conclusion to be reached.

CRYSTALLOGRAPHY

As noted, the crystals are frequently parallel or sub-parallel groups of flattened and elongated individuals, but a number of single ones were obtained for measurement. Ten of these were measured on the two-circle goniometer, and a number of others examined, but not measured, as they showed few faces and none which had not been previously observed. Because of the flattened prismatic habit the crystals are easily adjusted, but many of the readings, except on (010), were quite unsatisfactory. All crystals showed (010), and likewise a series of faces, usually very narrow and often indeterminate, in the prism and in the clinodome zones. Pyramids were noted on only two of the crystals measured, but so poorly developed as to give very unsatisfactory readings. One of these ($\bar{1}66$) may perhaps be considered sufficiently good to record, as its presence is confirmed by its development in the same zone on microscopic crystals. This zone is marked ($\bar{1}06$) in figure 1.

The side pinacoid faces (010) are usually good, but often characterized by panning, or striations parallel to the prism and clinodome zones, respectively. Figure 2 shows a typical crystal, although the striations are frequently not so pronounced.

Forms

Only those forms which occur frequently, or in good position, should be considered as established, and according to this criterion many observations made on these crystals must be discarded, or at least held in abeyance for future possible confirmation. Accordingly, only the probable forms have been indicated by letters, and occasional comment is made on their reliability.

1. $b(010)$. This form occurs on every crystal, usually on both sides. Readings are good, and the maximum variation is only a few minutes from 180° apart.

2. $n(120)$.

Observed		Calculated	
ϕ	ρ	ϕ	ρ
$73^\circ 34'$	$90^\circ 00'$	$74^\circ 23\frac{1}{2}'$	$90^\circ 00'$
75 08	90 00		
73 02	90 00		
73 00	90 00		
73 04	90 00		
<hr/>			
av. 73 45			

Readings only fair, but the form occurs five times, and may be considered established.

3. $k(140)$.

Observed		Calculated	
ϕ	ρ	ϕ	ρ
58°28'	90°00'	60°49'	90°00'
59 50	90 00		
59 58	90 00		
59 36	90 00		
59 46	90 00		

av. 59 32

4. $l(160)$.

ϕ	ρ	ϕ	ρ
49°46'	90°00'	50°02'	90°00'
50 38	90 00		
51 14	90 00		

av. 50 32

5. $g(013)$.

ϕ	ρ	ϕ	ρ
59°16'	34°54'	61°04'	34°31'
59 36	34 48		
59 16	35 04		
59 04	35 00		

av. 59 19 34 56

Agreement with calculated angle is poor, but (013) is by far the nearest to any relatively simple indices.

6. $h(023)$.

ϕ	ρ	ϕ	ρ
41°52'	41°50'	42°07½'	41°53½'
41 36	42 20		
43 36	41 30		
42 22	41 30		
40 54	42 05		

av. 42 04 41 51

7. $l(310)$.

ϕ	ρ	ϕ	ρ
87°26'	90°00'	87°20'	90°00'
88 10			

av. 87 49

8. $s(180)$.

ϕ	ρ	ϕ	ρ
42°02'	90°00'	41°47'	90°00'
42 32			

av. 42 17

9. *f*(014).

Observed		Calculated	
ϕ	ρ	ϕ	ρ
68°04'	32°56'	67°29'	33°05'
67 06	33 06		
<hr/>			
av. 67 35	33 01		

10. *d*(011).

ϕ	ρ	ϕ	ρ
33°56'	47°08'	31°05'	49°22'
32 44	48 04		
<hr/>			
33 20	47 41		

Not entirely satisfactory, but the nearest likely indices.

11. *j*(043).

ϕ	ρ	ϕ	ρ
24°20'	54°44'	24°20'	55°36'
24 52	55 16		
<hr/>			
av. 24 36	55 00		

12. *o*(031).

ϕ	ρ	ϕ	ρ
10°14'	72°09'	11°22'	71°52'
10 48	74 10		
<hr/>			
av. 10 31	73 10		

13. *q*(230).

ϕ	ρ	ϕ	ρ
79°54'	90°00'	78°10'	90°00'
77 04	90 00		
<hr/>			
av. 78 29			

14. (I66)

ϕ	ρ	ϕ	ρ
-30°16'	49°24'	-30°36½'	49°13½'

Included, because although measured only once, its zone has been observed on the microscopic crystals, and its agreement with the calculated position is good.

In addition to these, the base and pinacoid *a* occur only once each with a fair signal, but are nearly always represented in their respective zones by a continuous band of reflections. Other faces occurring only once, or marked by a brighter spot in the train of signals reasonably close to the calculated position, are the following: in the prism zone, (320), (110), (560), (130), (150), (170); in the clinodome zone, (0.1.30) [three readings, probably vicinal to 001], (017), (016), (027), (025), (035), (056), (065), (054); a pyramid, possibly (I.6.12.).

The accompanying angle table includes calculations for the better established forms only.

ELEMENTS AND ANGLE TABLE

$$a:b:c=0.163:1:0.998$$

$$\beta=121^{\circ}02'$$

$$p_0:p_0:r_0=6.1227:0.8551:1$$

$$\mu=58^{\circ}58'$$

$$r_2:p_2:q_2=1.1694:7.1599:1$$

$$p'_0=7.1455 \quad q'_0=0.9980 \quad x'_0=0.6017^*$$

Forms	ϕ	ρ	ϕ_2	$\rho_2=B$	C	A
<i>b</i> 010	0°00'	90°00'	—	0°00'	90°00'	90°00'
<i>l</i> 310	87 20	"	0 00	87 20	59 00½	2 40
<i>q</i> 230	78 10	"	"	78 10	59 42	11 50
<i>n</i> 120	74 23½	"	"	74 23½	60 14	15 36½
<i>k</i> 140	60 49	"	"	60 49	63 15	29 11
<i>t</i> 160	50 02	"	"	50 02	66 43½	39 58
<i>s</i> 180	41 47	"	"	41 47	69 54½	48 13
<i>f</i> 014	67 29	33 05	58 58	77 56	12 04	59 43
<i>g</i> 013	61 04	34 31	"	74 05	15 55	60 17
<i>h</i> 023	42 07½	41 53½	"	60 18½	29 41	63 23½
<i>d</i> 011	31 05	49 22	"	49 28	41 24½	66 56
<i>j</i> 043	24 20	55 36	"	41 15½	48 45	70 07½
<i>o</i> 031	11 22	71 52	"	21 17	68 42	79 12½
<i>p</i> 166	-30 36½	49 13½	120 33½	49 19½	40 41	112 40½

* In the abstract of this paper, printed for the December meeting, this value was given wrongly, due to an arithmetical error. The author.

NOTES AND NEWS

GRATONITE—PRELIMINARY DESCRIPTION OF A NEW MINERAL FROM CERRO DE PASCO, PERU

CHARLES PALACHE, *Harvard University*,

and

D. JEROME FISHER, *University of Chicago*.

The mineral here named was sent to the Harvard Mineralogical Laboratory for identification by Mr. Vance of Ward's Natural Science Establishment in October 1938. A little later specimens were received at Chicago by Dr. Fisher, sent by Dr. George W. Rust of the Geological Staff at Cerro de Pasco.

Preliminary examinations at both institutions have shown that the mineral is not jordanite as thought by Dr. Rust, from the study of its physical properties and analysis; and that it is not identical with any known species. The following data give its principal characteristics:

Hexagonal, rhombohedral. $a:c=1:0.4428$

Forms: a 11 $\bar{2}0$, m 10 $\bar{1}0$ (trigonal), c 0001, r 10 $\bar{1}1$, M 40 $\bar{4}1$, e 01 $\bar{1}2$, s 02 $\bar{2}1$

Angle $c \wedge r$ 27°04½' $c \wedge s$ 45°38'

The principal forms are the prism and the rhombohedron s 02 $\bar{2}1$, which is not selected as unit form on the basis of x -ray study of the unit cell. Twinning not seen.

Cleavage none. $H=2\frac{1}{2}$. $G=6.22$. Color dark lead gray. Streak black.

Composition $Pb_9As_4S_{16}$ on basis of two closely agreeing analyses, the one by the chemist of the Cerro de Pasco Corporation, the other by F. A. Gonyer in the Harvard Laboratory.

A more detailed description will appear shortly. The name *gratonite* is in honor of L. C. Graton, Professor of Mining Geology at Harvard University. This name has already appeared in print in the *New York Times*, December 28, 1938.